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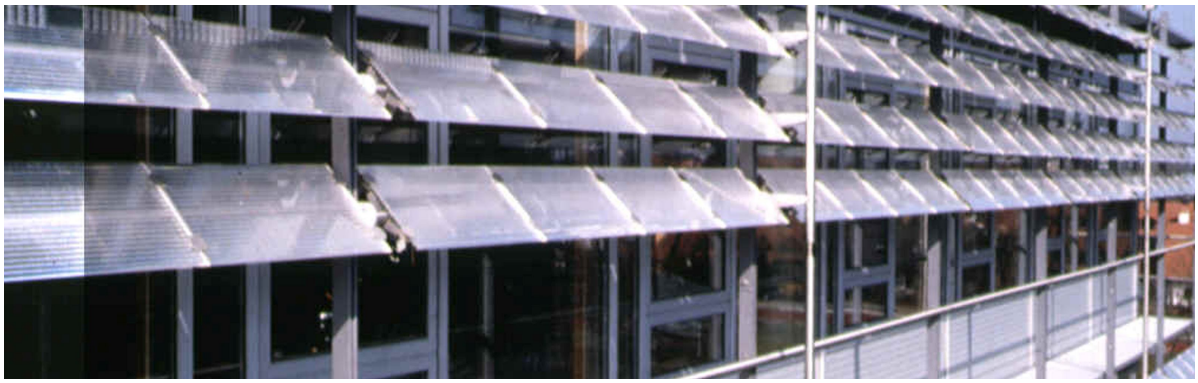

PERFORMANCE EVALUATION OF SOLAR SHADING SYSTEMS

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Abstract

This dissertation is composed of two parts: Part A and Part B. In Part A, a user-friendly method of how to evaluate the performance of different solar shading systems during an early design phase of a building is illustrated. The method is based on the use of *WIS* and *BuildingCalc/LightCalc* simulation tools. The solar shading systems integrating a building may be dynamically controlled and the energy and daylight performances of the building may be evaluated.

A case study of a landscaped office building in which different solar shading systems were tested is presented. The building was studied for two different climates (Copenhagen and Lisbon). It is clear the difference when comparing different solar shading systems and different climates.

Nowadays, there is still a lack of information about the thermal/optical properties of solar shading systems. Some examples and suggestions of how to use the simplified data available are presented. The results, compared with the use of complete data, show that the difference on the final performance of the building is not significant. However, more research should be done in this field as only few cases were studied.

The glass lamellas are a promising type of solar shading system that demands for more precise daylight evaluation using raytracing tools. In Part B of this dissertation, daylight measurements for glass lamellas systems performed in the experimental rooms of the Daylight Laboratory at SBi (Danish Building Research Institute) were compared with *IESve/Radiance* simulations. Results show that *IESve/Radiance* may be used to evaluate the daylight performance of glass lamellas systems in most situations.

Keywords

Solar shading systems, office buildings, energy, daylight, glass lamellas, *WIS*, *BuildingCalc/LightCalc*, *IESve/Radiance*

Resumo

Esta dissertação é composta por duas partes: Parte A e Parte B. Na Parte A, é apresentado um método simples de como avaliar o desempenho de diferentes sistemas de sombreamento solar numa fase inicial de projecto. O método baseia-se na utilização de duas ferramentas: *WIS* e *BuildingCalc/LightCalc*. Os sistemas de sombreamento solar integrados num edifício podem ser automaticamente controlados e o seu desempenho energético e em termos de trasmissão de luz natural pode ser avaliado.

Um caso estudo de um edifício de escritórios do tipo open-space no qual diferentes sistemas de sombreamento solar foram testados é apresentado. Foram estudados dois climas distintos (Copenhaga e Lisboa). É nítida a diferença entre os dois climas assim como entre tipos distintos de sistemas de sombreamento solar.

Hoje em dia, existe falta de informação no que diz respeito às propriedades témicas e ópticas de sistemas de sombreamento solar. São apresentados alguns exemplos e sugestões de como usar a informação disponível. Os resultados, comparados com o uso de informação completa mostram que a influência no desempenho global do edifício é mínima. No entanto, poucos casos foram estudados e mais investigação deve ser feita nesta área.

Os sistemas de sombreamento solar compostos por lamelas de vidro são soluções promissoras e exigem uma avaliação mais precisa no que diz respeito ao desempenho face à transmissão de luz natural para o interior dos edifícios. Esta avaliação pode ser feita com recurso a ferramentas de raytracing. Na Parte B desta dissertação, medições do nível de iluminação natural feitas no Laboratório de Luz Natural do SBi (Danish Building Research Institute) para avaliar o desempenho de lamelas de vidro foram comparadas com simulações utilizando o programa *IESve/Radiance.* Os resultados mostram que, na mairoria das situações, este programa pode ser utilizado para avaliar o desempenho de lamelas de vidro no que diz respeito ao comportamento face à luz natural.

Palavras-chave

Sistemas de sombreamento solar, edifícios de escritórios, energia, iluminação natural, lamelas de vidro, *WIS*, *BuildingCalc/LightCalc*, *IESve/Radiance*

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List of Symbols

A	Area [m^2]
b.	Back surface of the solar shading system
B	Blue
B-Refl	Blue reflectance [-]
B-tn	Blue transmissivity [-]
c	Slat crown height [mm]
c_w	Specific heat capacity of the water [J/kg.ºC]
C_f	Heat capacity of furniture [J/K]
C_w	Heat capacity [J/K]
DLfactor	Daylight factor [%]
DLfactorSS	Daylight factor for sunny sky [%]
E	Illuminance [lux]
E_t	Total energy consumption [kWh/m^2.year]
E_h	Energy consumption for heating [kWh/m^2.year]
E_{hor}	Global (horizontal) illuminance [lux]
E_c	Energy consumption for cooling [kWh/m^2.year]
E_l	Energy consumption for electrical lightning [kWh/m^2.year]
E_{mv}	Energy consumption for mechanical ventilation [kWh/m^2.year]
E_{hw}	Energy consumption for hot water [kWh/m^2.year]
E_{vert}	Vertical illuminance [lux]
f.	Front surface of the solar shading system
FF	Shape factor (“factor de forma”) [-]
g-value	Solar heat gain coefficient [-]
G	Green
G-refl	Green reflectance [-]
G-tn	Green transmissivity [-]
L	Luminance [cd/m^2]
n	Total number of working hours of the mechanical ventilation system [h]
OF	Openness factor [%]
PPD	Predicted percent of dissatisfied [%]
IR-radiation	Infrared radiation
IR ε_{ind}	Indoor infrared emissivity [-]
IR ε_{out}	Outdoor infrared emissivity [-]
IR trans	Infrared transmissivity [-]
R	Red
R-refl	Red reflectance [-]

RD	Relative difference [%]
RGB-refl	Red, green and blue reflectances when they are equal [-]
Ra	General colour rendering index [%]
Rough	Roughness [-]
R-tn	Red transmissivity [-]
SEL	Specific electrical power consumption for air transport [kJ/m^3]
Spec	Specularity [-]
SSC	Solar shading coefficient [-]
Stdev	Standard deviation [-]
t	Thickness [mm]
tn	Transmissivity [-]
Tr-spec	Transmitted specularity [-]
T	Temperature [ºC]
Tn	Visual transmittance [-]
U-value	Thermal transmittance coefficient [W/m^2K]
UA-value	Sum of thermal transmission losses through the façade excluding windows [W/K]
UV-radiation	Ultraviolet radiation
V	Volume [m^3]
VSC	Visual shading coefficient [-]
w	Slat width [mm]
p	Slat pitch - distance between slats [mm]
α	Slat angle [º]
α_c	Cut-off angle [º]
β	Solar altitude angle [º]
α_s	Solar absorptance [-]
α_v	Visual absorptance [-]
α_{uv}	Ultraviolet absorptance [-]
ΔT	Temperature increase needed for the production of hot water [ºC]
φ	Angle of incidence [º]
γ	Solar azimuth angle [º]
θ	Profile angle [º]
λ	Thermal conductivity [W/mK]
ρ_s	Solar reflectance [-]
ρ_v	Visual reflectance [-]
ρ_{uv}	Ultraviolet reflectance [-]
τ_s	Solar transmittance [-]
τ_v	Visual transmittance [-]
τ_{uv}	Ultraviolet transmittance [-]

PART A. ENERGY AND DAYLIGHT PERFORMANCE EVALUATION OF SOLAR SHADING SYSTEMS

1. Introduction

1.1 Background

Energy savings are essential for the general long term solution of the problems with use of energy from fossil fuels.

In buildings, to maintain a good indoor environment, energy is used for heating, cooling and electrical lighting. This requirement for indoor comfort is especially important in large office buildings: it is known that the indoor comfort has a large influence on the workers motivation and efficiency levels. In this way, if the office buildings are not carefully designed the yearly total energy consumption can reach very high levels.

To assure a high energy performance of buildings not only the insulation of the building envelopment is important but also other components as the ventilation, heating and cooling systems are significant.
However, the “weakest” parts of the buildings are the windows. They are incorporated in buildings to provide indoor daylight and a good view out. In theory, larger the windows are, less the demand for electrical lightning is.
The drawback of windows is that the heat losses and the solar heat gains occur mainly through them. If they are not carefully designed they can largely influence the building energy demand for heating and cooling. To avoid the heat losses, the windows must have a low thermal transmittance coefficient while solar shading systems must be applied to decrease the unwanted solar gains.

The solar shading systems are the central part of this dissertation. If they are not correctly used they can have no positive effect or even a negative effect on the overall performance of buildings.
First of all, the solar shading systems must be flexible to different exterior conditions. They need to be activated especially during warm and sunny days to block the solar gains and, consequently, avoid the overheating. On the other hand, during cold and sunny days it should be possible to retract them in order to allow the solar gains to enter the building, reducing in this way the heating demand.
Another problem is often associated with the use of solar shading systems: when activated to block the sun rays and avoid the solar heat gains and overheating, the solar shading systems also block the light. In this way, the need for electrical lightning increases. The critical point is when the increase on electrical lightning demand is higher than the decrease on cooling demand caused by the use of the solar shading system. In this situation it is not worthy to have a solar shading system: besides the higher total energy consumption, the indoor natural light level is lower and the view out is obstructed (which are the main purposes of having a window).

A solution that provides a balance between solar gains and daylight level must be found. It is very important that the most appropriate solar shading system is chosen for each situation and this procedure should be simple and done early in the design phase.

The Department of Construction and Architecture from Lund University already developed a tool, *Parasol*, for this purpose. *Parasol* is a user friendly interface which is able to calculate the properties of windows systems composed of different solutions of glazings and shading devices. The different window systems can be integrated in a simple model of a room and yearly simulations can be performed giving as a result the room yearly energy demands for heating and cooling.

In this dissertation the combination of *WIS* (Window Information System) with *BuildingCalc/LightCalc* will be used.
WIS is a tool that calculates the properties of window systems based on the properties of their components. *WIS* includes databases with detailed information for some windows components available in the market as glass panes, shading systems, frames and spacers.
BuildingCalc/LightCalc is a tool that is able to assess the performance of buildings in which windows from *WIS* can be integrated and as in *Parasol* yearly simulations may be performed.
The main advantage of *BuildingCalc/LightCalc* comparing to *Parasol* is that also the daylight level inside the room can be evaluated and if it does not fit the requirement, electrical lightning will be automatically switched on. Also the yearly energy demand for electrical lightning is calculated. This is very important when assessing the performance of solar shading systems: when using shading systems the decrease in the cooling demand should be higher than the consequent increase in electrical lightning demand.
Using *WIS* and *BuildingCalc/LightCalc* it is easy to evaluate the performance of different solar shading systems and select the best option for each specific building. However, it is not easy for the designer to find information about the thermal/optical properties of the solar shading systems available in the market: most of the manufactures do not have the thermal properties of their products available and regarding optical properties only integrated data is available. Only few manufactures have the complete data available in databases.

1.2 Goal

The goal of the PART A of this dissertation is to illustrate a simple method on how to assess the performance of different solar shading systems when designing a building.
The method is based on the use of two different softwares: *WIS* (which is able to calculate thermal/optical properties of windows systems based on the properties of their components) and *BuildingCalc/LightCalc* (a software developed at BYG.DTU that can perform yearly simulations for a defined building giving as a result the energy demand for heating, cooling and lightning and still indoor comfort evaluation parameters). The link between both softwares is that the window systems assessed in *WIS* can be integrated in the building defined in *BuildingCalc/LightCalc*.

As a case study, a landscaped office room will be simulated for different solutions of solar shading systems. The same office room will be studied for two different locations: Copenhagen (representing a north Europe location) and Lisbon (representing a south Europe location).
The result will be the performance of the building in both climates when using different solutions of solar shading systems.

Some tips on how to use both softwares for the purpose before referred will be presented (including some step-by-step examples). Also some suggestions will be given on how to overcome the lack of information characterizing the solar shading systems available in the market.

2. Brief introduction to the different types of solar shading systems

2.1 Overview

There are many different kinds of solar shading systems available in the market. When designing a building besides the aesthetical component, also the energy performance and indoor comfort including temperature and daylight must be taken into account.

A solar shading system must be able to control the solar heat gains in order to reduce the risk of overheating and the energy needs for cooling and at the same time control the indoor daylight and avoid glare. [1]
The optimum solution is a balance between these factors. According to [21], usually the products that have low solar transmittance values (g-value) admit almost no daylight into the room and totally obstruct the view out, which are two of the main purposes of windows. The problem comes when the energy needed for electrical lightning increases more than the decrease of energy for cooling originated by the solar shading systems.

The solar shading systems should be as flexible as possible so they can adapt to the outdoor conditions. In this way, they could be activated in summer sunny days to avoid overheating and glare and retracted during overcast days to increase the daylight level inside the room. During the winter they should also allow some solar gains to enter the room as a way of reducing the heating load.
When completely activated at night some solar shading systems may contribute to decrease the thermal transmittance coefficient (U-value) of the window. In this way, the heat losses through the window (from the interior to the exterior of the building) are reduced and, subsequently, also the heating demand.

The solar shading systems may be characterized depending on their position in the window. Thus, in accordance with [20] and [21] they can be separated into three groups: external, interpane and internal. As the group names indicate the external are the ones placed on the external (ambient) side of the window, the interpane are the ones placed inside the glazing cavity (between panes) and the internal are the ones placed on the internal (room) side of the window.

According to [21], the external solar shading systems are the most efficient in reducing the cooling loads. As they are placed outside they reflect the solar rays before they enter the room. Also the heat they absorb is dissipated to the outside air by radiation and convection. (**Figure 2.1**) Their main drawback is that, as they are placed outside, they are more exposed to the atmosphere

conditions which can lead to an easier deterioration and higher need for maintenance. As a result they need to be more robust.

Also in accordance with [21] the interpane and internal solar shading have a lower efficiency in terms of avoiding the solar gains. This is due to the reflected radiation that has to pass through the glass to reach the outdoor environment. Simultaneously, and especially in the internal systems, the heat absorbed by the shading system is radiated and convected to the inside of the room (see **Figure 2.1**). According to [21] these systems should be used as a component of external devices and their main advantage is the ability to control the amount of daylight and glare inside the room.

Because of their position on the windows the interpane and internal devices are protected against the outside conditions and almost do not require maintenance. The interpane solutions placed in sealed glazing units are free from damage and dirt and do not require to be cleaned.

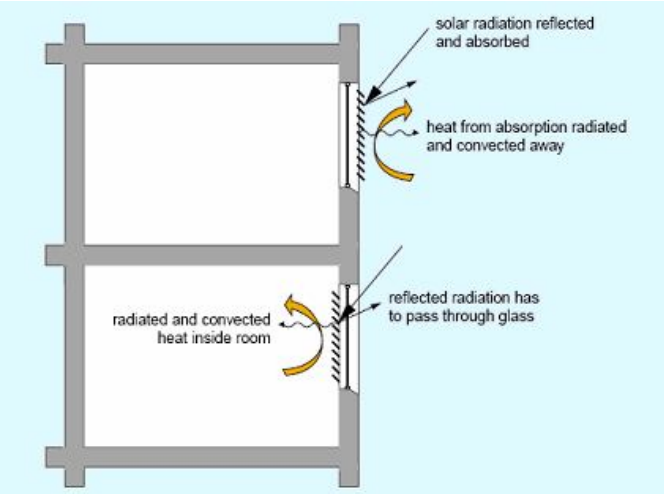

Figure 2.1- Heating transfer phenomena that occur on external (above) and internal (below) solar shading systems [12]

The solar protective glazings are not included in the groups described before but also constitute a type of solar shading system. They are integrated in the window, replacing the panes.

The types of solar shading systems evaluated in this dissertation and its main characteristics are next presented. These are just a very small part of what is available in nowadays market, but are the ones that are possible to simulate with the used software (*WIS* and *BuildingCalc/LightCalc*).

2.2 Venetian blinds

A venetian blind is a blind composed of parallel spaced slats that can be tilted in order to control the amount of solar gains and light entering the room.
The slats are available in different widths and can be made of different materials (usually wood or aluminium). They are also available with different finishes and colours according to the wanted esthetical effect.
The venetian blinds have the great advantage of being retractable and they can be internal, external or interpane (see **Figure 2.2**). According to the place where they are going to be mounted they have different requirements. For instance an external venetian blind needs to be more resistant and robust (higher width and thickness) than an internal one.
A narrower slat will reduce the view of the outside when the slat is angled for effective solar protection.

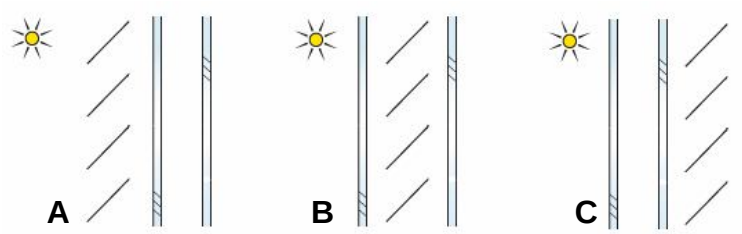

Figure 2.2 - Schemes of external (A), interpane (B) and internal (C) venetian blinds [40]

The slats can be also vertical, but its calculations are not yet implemented in the *WIS* software. The reason for this is that angular calculations are only performed for different altitude angles. The azimuthal angle is always assumed to be normal to the window. Therefore, variations in the angle of incidence (altitude angle) have no effect on the transmission and reflection of vertical blinds [17].

2.3 Roller blinds

A roller blind is a retractable blind made of a flexible material which is flat when drawn.
They are available in different fabrics which can be more or less transparent according to their openness factors. The fabrics can have a metallic or non-metallic finish and are available on different colours.
The roller blinds can be external, internal or interpane (see **Figure 2.3**), but they have different requirements depending on where they are going to be mounted. For instance, a roller blind for external use should have a higher thickness and a more resistant finish. It should also be mounted in side runners so it is more protected from the wind loads.

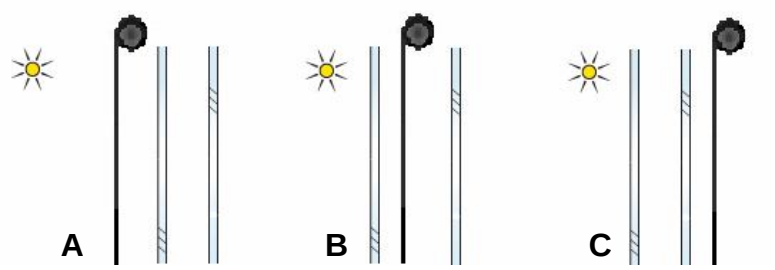

Figure 2.3 - Schemes of external (A), interpane (B) and internal (C) roller blinds [17] and [40]

2.4 Glass lamellas

The glass lamellas are another type of external solar shading systems (**Figure 2.4**). They are composed of orientable glass lamellas supported by a metallic structure. Besides controlling the solar gains contributing to reduce the overheating and the energy demand for cooling, they also control the daylight. They may improve the daylight conditions by redirecting the light further into the room where it is most needed.[18]

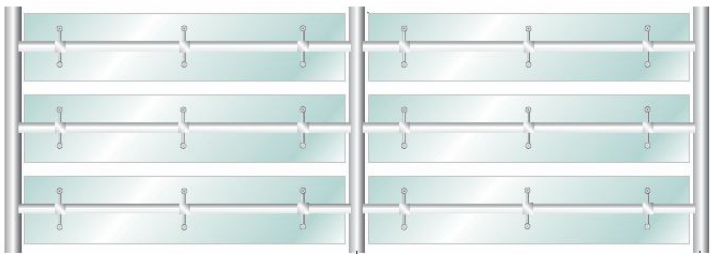

Figure 2.4 - Glass Lamellas - Model *CARRIER SYSTEM 1* from COLT manufacturer [24]

The glass lamellas can be set in different angles according to the function they need to perform. Thus, in sunny days they can be tilted as a solar shading system in order to block the direct sun rays, while in overcast days they can be tilted in a way that they reflect the daylight into the room increasing the indoor daylight levels especially far from the window (see **Figure 2.5**).
The solar transmittance of the glass lamellas is reduced adding to its surface black dots (silkscreen printed pattern) or solar control coatings next described.

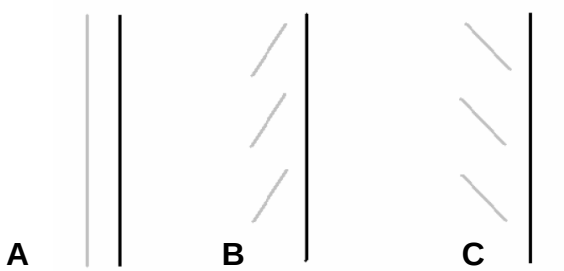

Figure 2.5 - Glass Lamellas in solar shading position (A and B) and in daylight position (C) [18]

2.5 Solar control glass

The solar control glass is also a way of controlling the solar gains reducing the risk of overheating and the energy demand for cooling. This type of glass has a low transmittance in the near infrared reducing the solar heat gains [12].

At the same time a solar control glass should have a high visible light transmittance in a way that it does not compromise the daylight inside the room.

In **Figure 2.6**, **Figure 2.7** and **Figure 2.8** the diagrams of spectral transmittance, reflectance and absorptance are presented for a solar protective glass used in this dissertation. The graphs show that it is a selective glazing with higher transmittance in the visible part of the spectrum and lower on the infrared and ultraviolet parts.

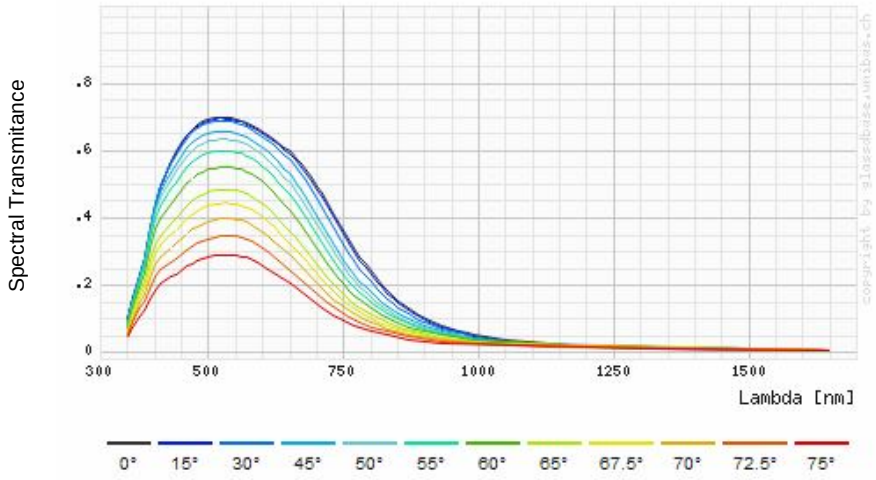

Figure 2.6 - Spectral transmittance depending on the angle of incidence, φ, for the *Pilkington: Suncool Brilliant 66/33* solar control glass [27]

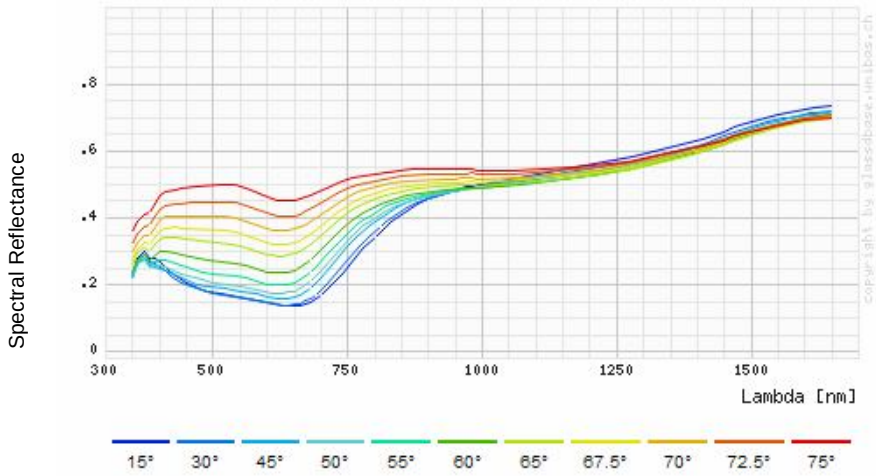

Figure 2.7 - Spectral reflectance depending on the angle of incidence, φ, for the *Pilkington: Suncool Brilliant 66/33* solar control glass [27]

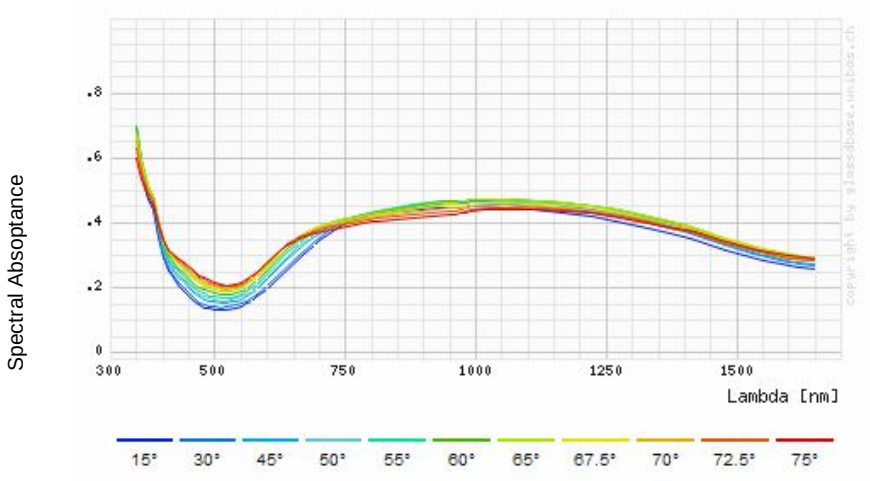

Figure 2.8 - Spectral absorptance depending on the angle of incidence, φ, for the *Pilkington: Suncool Brilliant 66/33* solar control glass [27]

The solar protective glasses studied on this dissertation were the body-tinted glasses and the reflective glasses.

2.5.1 Body-tinted glass

The body tinted glass is a normal float-clear glass into whose melt colorants were added for tinting and solar-radiation absorption properties. This reduces heat penetration in buildings. These coloured glasses are an important architectural element for the exterior appearance of façades but they have a significant negative effect on the colour of the transmitted light. [26]

2.5.2 Reflective glass

The reflective glass is an ordinary float glass with a metallic coating to reduce solar heat. This special metallic coating also produces a mirror effect.

There are two different types of coatings: hard coatings (on-line coated) and soft coatings (off-line coated).

The hard coating glasses result from a pyrolitic process in which semi-conducted metal oxides are directly applied to the glass during the float glass production while the glass is still hot. These hard coatings are very resistant to mechanical damage and relatively harmful to the environment.

The soft coatings glasses are originated from a vacuum (magnetron) process in which one or more coats of metal oxide are applied under a vacuum to finished glass. The coatings applied by this technique are soft and must be protected against external influences and are therefore used in sealed glazing units. [17]

2.6 Market search

In **Table 2.1**, a list of some manufactures that have the products described before available is presented.

Table 2.1 - Examples of manufactures for the solar shading systems studied

Type of solar shading	Position	Manufacture	Website
Venetian blinds	External	Hunter Douglas Contract	http://www1.hunterdouglascontract.com
		Warema	http://www.warema.de
	Interpane	Hagen	http://www.hagen.dk
		Luxaclair	http://www.luxaclair.co.uk
		Hunter Douglas Contract	http://www1.hunterdouglascontract.com
	Internal	Luxaflex	http://www.luxaflex.com
		Velux	http://www.velux.com/
		Hunter Douglas Contract	http://www1.hunterdouglascontract.com
Roller blinds	External	Verosol	http://www.verosol.com
	Interpane	Pellini	http://www.pellini.net
	Internal	Verosol	http://www.verosol.com
		Velux	http://www.velux.com/
Glass lamellas	External	Colt	http://www.coltinfo.co.uk
		Hunter Douglas Contract	http://www1.hunterdouglascontract.com
		Saint Gobain Glass	http://www.saint-gobain-glass.com
Solar control glazings	-	Pilkington	http://www.pilkington.com
		Saint Gobain Glass	http://www.saint-gobain-glass.com

The evaluation of the performance of different solar shading systems is somehow limited by the lack of information given by the manufactures about the thermal and optical properties of the different materials that compose their products. *WIS* has an integrated database where some manufactures have already added the data for their products but this should be widened to more and more manufactures.

Regarding glazing it is easier to find spectral information available. *WIS* has a database for it and there is a database named *Glassdbase* [26] also with some information about it. This last one is a database with data on commercial insulating glasses determined at the Institute of Physics at the University of Basel, Switzerland and it is focused on sun protection glasses.

3. Some useful definitions

When characterizing and evaluating the performance of glazings and solar shading systems there are some standard terms usually referred by manufactures and designers. These terms which will be used throughout this dissertation are next described.

3.1 Electromagnetic spectrum

The electromagnetic spectrum can be divided into wavelength intervals:
1) λ<380nm (UV-radiation) - this is the non-visible ultraviolet radiation and it has a little meaning for the energy balance of buildings. However, this is the part of spectrum responsible for the long term colours change of buildings furniture. It can be harmful for people
2) 380nm<λ<780nm (visible radiation) - this wavelength interval represents the visible light and it contains around 50% of the solar radiation. It is important that windows have a high transmittance in this wavelength range to allow a high indoor daylight level.
3) 780nm<λ<2500nm (near-infrared radiation) - this part of the solar radiation is not visible and it represents approximately 40% of the energy from the sun.
4)λ>2500nm (IR-radiation) - all the surfaces at room temperatures emit energy in this interval. Ordinary window glass is not transparent for these wavelengths; however, the radiation is absorbed and then re-radiated towards indoor and outdoor environments. A major part of the heat loss through an ordinary window occurs in this way. [1]

3.2 Reflectance, absorptance and transmittance

The glazings and the materials that compose the shading systems can be characterized according to their solar-optical properties: reflectance, absorptance and transmittance.
The reflectance (ρ) is the fraction of the incident flux that is reflected from the glazing or shading material, the absorptance (α) is the fraction of incident flux absorbed by the glazing or shading material and the transmittance (τ) is the fraction that is transmitted through them. The sum of the reflectance, absorptance and transmittance must be equal to the unit ($\rho+\alpha+\tau=1$).
The solar transmittance (τ_S) is the glazing or shading material transmittance over the whole solar spectrum while the visual transmittance (τ_V) refers to the transmittance only for the visible range of the solar spectrum. In a similar way also the ultraviolet transmittance (τ_{UV}) can be defined.
Manufacturers usually give the visual transmittance because it determines how well one can see through a window and how much natural light can be used in the building to illuminate tasks. [6]

3.3 Thermal transmittance coefficient

The thermal transmittance coefficient, U-value, is the amount of heat that passes through an element per unit area and per unit time when the temperature difference between the environments separated by the element is 1 Kelvin. This parameter takes into account the surface resistances and the conduction, convection and radiation phenomena. It is usually defined in W/m^2K. [16]

3.4 Solar heat gain coefficient

The solar heat gain coefficient, g-value, is the fraction of incident irradiance (solar radiation incident on the glazing) that enters the building and becomes heat in the space. It includes both the directly transmitted portion and the absorbed and re-emitted portion of solar radiation. [6]

3.5 Solar shading coefficient

The solar shading coefficient, SSC, is sometimes defined as the ratio between the g-value of a window system (glazing + solar shading device) for a particular angle of incidence and the g-value of a reference clear float glass (3mm thickness) for the same angle of incidence. [6]
However, in this dissertation it was assumed to be the ratio between the g-value of the window system and the glazing initially selected as the reference. In this way, the reference glazing has a shading coefficient of 1 and it is easier to compare the performance of the different solutions.
Lower solar shading coefficients indicate higher performances.

3.6 Visual shading coefficient

The visual shading coefficient, VSC, is defined in a similar way as the solar shading coefficient. It is the ratio between the light transmittance of the window system and the light transmittance of the glazing initially defined as the reference. In this way, for the reference glazing, the visual shading coefficient is 1. Higher visual shading coefficient indicates higher visual performance.

3.7 General colour rendering index - Ra

This index is used to assess quantitatively the performance of colour rendering through a window system.
A Ra index of 100% corresponds to perfect colour preservation. [27]

3.8 Illuminance

Illuminance, E, describes the amount of luminous flux arriving at a surface, i.e., the incident flux per unit area. It is measured in lux. [1]

3.9 Luminance

Luminance, L, describes the light reflected off a surface and it is directly related to the perceived “brightness” of a surface in a given direction. It depends on the illuminance on an object and its reflective properties. Luminance is what we see, not illuminance. Luminance is measured in candelas per square meter (cd/m^2). [1]

3.10 Daylight Factor

The daylight factor, DLfactor, is the ratio of the illuminance on a surface in a room to the illuminance on an external unobstructed horizontal surface, taking only the diffuse radiation into account. This parameter is usually calculated for evaluating the daylight performance of window systems under overcast skies when only diffuse light exists. [1]

3.11 PPD index

The PPD index (predicted percent of dissatisfied), defined in %, takes into account the influence of all 6 thermal parameters (clothing, activity, air- and mean radiant temperature, air velocity and humidity) and it may be directly used as a indoor comfort criteria [14]

4. Method to evaluate the performance of different solar shading systems

4.1 The Sofware used - Relation between *WIS* and *BuildingCalc/LightCalc*

To evaluate the performance of different solar shading systems two softwares were used: *WIS3.0.1* (developed by TNO Building and Construction Research in Delft) [41] and *BuildingCalc/LightCalc v2.3.1f* (developed in Matlab at Technical University of Denmark) [38].

WIS is a European software tool for the calculation of the thermal and solar properties of window systems.
Knowing previously from the manufactures spectral data for the thermal and optical properties of the materials that compose the different shading systems and also the properties of the glazing (panes and gaps), it is possible to calculate the properties of combined systems (glazing+shading system) for different angles of incidence. Concerning shadings composed of slats that can be tilted it is also possible to calculate the properties for different positions of the slats. [3]

BuildingCalc/LightCalc is a tool that can be used in three different ways: only *BuildingCalc* (for thermal simulations), only *LightCalc* (for daylight simulations) and *BuildingCalc/LightCalc* (for combined simulations).
With *BuildingCalc/LightCalc* it is possible to create a simple model of a room and import from *WIS* the properties of the solution for the window (glazing+shading system). In an hourly basis dynamic simulation *BuildingCalc/LightCalc* is able to calculate the needs for heating, cooling and lightning during one whole year. Also an evaluation of the indoor comfort is made and parameters as total hours of overheating and PPD index (predicted percent of dissatisfied) are calculated. The indoor daylight conditions can also be studied for a specific day and hour. [11]

Combining these two softwares it is possible to do some calculations early in the design phase to evaluate and compare the energy and daylight performances of different solutions of solar shading systems.

4.1.1 WIS

With *WIS* it is possible to simulate a complete window system including glazing, solar shading system, frame and spacers. However for posterior use in *BuildingCalc/LightCalc* only the transparent system (solar shading + glazing) is necessary to be set. The properties of the frame and spacers are set separately in *BuildingCalc/LightCalc*.

Thus, in this dissertation the objective of using *WIS* is to generate text files that characterize the *transparent systems* (glazing + solar shading) in a way that they can be used in *BuildingCalc/LightCalc*.

In *WIS* there are already available databases with commercial solutions for the different components of a window (solar shading systems, panes of glass, frames and spacers). This information which includes geometrical, thermal and spectral optical properties of the components can be added by the manufactures and it is a precious help for the designers. However, still few manufactures have their information available on *WIS* databases.

It is also possible for the designer to add products to the database. But due to a lack of information about the properties of products by the solar shading systems manufactures this process is sometimes difficult for the designer. The optimum solution would be that the manufactures knew the properties of their solutions and had them in databases.
This is a problem essentially regarding the solar shading systems manufactures. For the glass this information is easier to find.
One solution would be to set up a product standard that requires documentation of spectral and angular optical data and that also requires the manufactures to CE-mark the products sold in the European Union.

4.1.2 BuildingCalc and Light Calc

In this dissertation *BuildingCalc/LightCalc* was used in two different versions: *combined simulations* for determination of the heating, cooling and lightning needs, number of hours of overheating and PPD index; and *light simulations* to evaluate the daylight performance of the different solar shading systems under critical sky conditions.

In this software, the simulation of thermal conditions is based on a simple thermal model of the room. The building envelope is simply defined by an overall UA-value that takes into account the sum of the thermal transmission losses through the façade excluding the window. The losses through the window are characterized separately. The heat capacity of the construction and the internal surface area are also defined.

It is possible to set different systems: heating, cooling, ventilation with air variable volume and heat recovery, venting and variable solar shading. The solar shading is the main focus of this dissertation. The systems are controlled by different settings which can be specified for different periods. This means that different control settings can be defined for summer and winter time and for working hours and non working hours.
It is possible to plot and export the results from the simulations in an hourly basis.
The location and weather data need also to be set.

The *LightCalc* component, based on the radiosity method, is able to estimate daylight levels in a room under different sky conditions.

BuildingCalc/LightCalc results from the combination of the features of *BuildingCalc* with *LightCalc*. In this way, the daylight levels will be estimated taking into account the shading control and consequently this will have an influence on the electrical lightning demand. Also the extra heat gain from the electrical lightning is taken into account. [11]

In **APPENDICES A**, **B**, **C** and **D**, some examples of how to use *WIS* and *BuildingCalc/LightCalc* are presented.

In **APPENDIX A**, a step-by-step example of how to use *WIS* and *BuildingCalc/LightCalc* for the purpose of this dissertation is presented. The given example refers to an internal venetian blind applied on the glass façade of the landscaped office building described on chapter **5. Case Study - Landscaped Office Building**.

In **APPENDIX B**, the way how to add a new shading system to the *WIS* database is presented.

In **APPENDIX C**, an example of how to model glass lamellas from glass pane properties (using *WIS*) is presented.

In **APPENDIX D** some tips are given on how to import the glass lamellas to *BuildingCalc/LightCalc.*

5. Case study - Landscaped office building

Office buildings with glass façades are more and more common. The transparent properties of the glass enable the natural light to come into the buildings allowing high levels of indoor daylight which is positive: it is known that people prefer working and have higher efficiency under natural light, and at the same time the cost for electricity and the CO_2 emissions decrease.
The drawback is that the glass façade is where the main solar gains and heat losses occur. The solar gains during winter are useful in decreasing the need for heating. But during summer the excess of solar gains give raise to many hours of overheating. The indoor comfort could be simple reached with an air-conditioning system, but this would lead to very high energy consumption for cooling. A solar shading system main goal is to reduce the need for cooling, avoiding the solar gains to get into the building.
At the same time the shading systems can control the daylight in buildings avoiding glare problems. If completely activated outside the working hours they improve the U-value of the window system, decreasing the heat exchanges between the inside and outside of the building.

5.1 Settings for Copenhagen

The test room will be a storey of a landscaped office building with a rectangular form located in Copenhagen (North Europe). Also a study of the same building but located in Lisbon (South Europe) will be done.
Next, the characteristics for the building located in Copenhagen are presented. The building in Lisbon has almost the same properties apart from some changes later presented.
The main goal is that the building is a relative high performance one according to energy and indoor comfort points of view. According to energy it should fulfil the energy frame for Denmark and Portugal. Regarding indoor comfort [14] the building should fulfil Category II, which means “Normal level of expectation”.

5.1.1 General information and dimensions

The building will have only one façade and it will be facing south. The rest of the boundary walls will be in contact with heated spaces.
It was assumed that near the front façade there are no other buildings/elements that could in someway originate shades on the building being studied.
It was also assumed that the building would have three storeys and instead of choosing one of them for the simulations it was created one that could represent the three at the same time. Thus, it was assumed that the representative storey would have 1/3 of its ceiling in contact with outside and

1/3 of its floor in contact with the ground. The remaining parts of the ceiling and floor were assumed to be in contact with heated spaces.

The inner dimensions of the room will be 20m width (so that the lateral walls will not have any influence in the daylight distribution inside the room), 10m depth (so that the critical point for lightning is included) and 3.3m height. (see **Figure 5.1**)

In this way, the landscaped office room has a floor area of 200m^2. It was assumed that 15 people will be working there, which means approximately a floor area of 13m^2 per person.

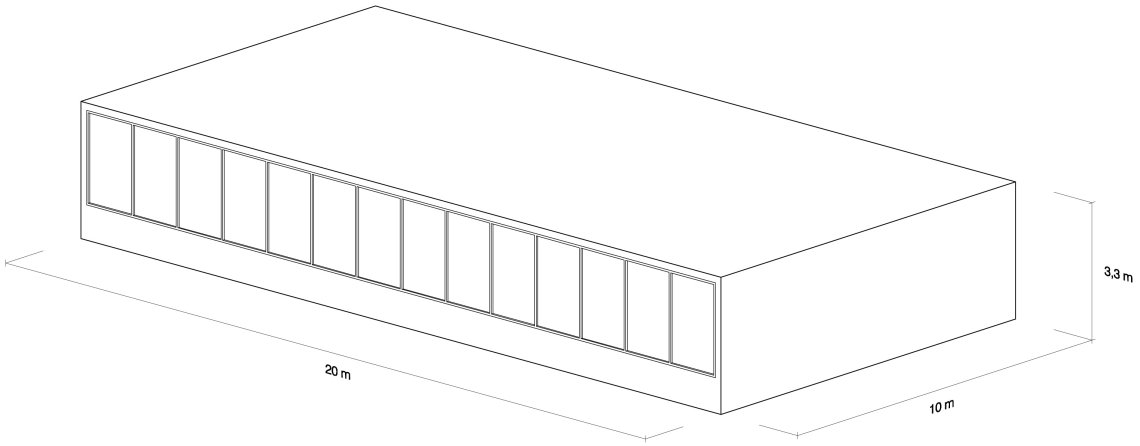

Figure 5.1 - Room drawing

5.1.2 The window (glazing and frame)

The window will occupy most of the façade. It will be 19.65m wide and 2.275m high. It will be 0.85m offset from the floor and 0.175m from the lateral walls and ceiling. It will be 0.10m inside the wall and no overhangs were considered. (see **APPENDIX E** where a detailed drawing of the façade is presented)

The window is on purpose placed upper most in the façade. The working plane will be around the 0.85m offset from the floor. A window below that level does not increase the daylight level in the working plane and leads to major overheating and heating losses. The most efficient solution for indoor daylight is to place the window as high as possible.

The reference glazing will be a triple pane one with a total thickness of 39.55mm. The outer panes will have low-e coatings on the internal surfaces. The inner pane will be a clear one. The gaps will be filled with 90% of argon and 10% of air. The different components of the glazing come from *WIS* software and are presented in **Table 5.1**. The properties of the glazing are shown in **Table 5.2**.

Table 5.1- Composition of the reference glazing for the test room façade

layer	description	width (mm)	coating position *
pane	Optitherm SN 4	3.85	UC
gap	Air/Argon 10/90	14	
pane	clear_04.gvb	3.85	UU
gap	Air/Argon 10/90	14	
pane	Optitherm SN 4	3.85	CU

*****the letters U and C mean *Uncoated surface* and *Coated surface* respectively, the first letter refers to the outer surface of the glass pane and the second to the inner one

Table 5.2 - Properties of the reference glazing for the test room façade

property	value
U-value [W/m^{2}K]	0.68
g-value [-]	0.49
τ_v [-]	0.68
Ra [%]	96

The frame used is *FWT 50-1 HA E-Plus*, a certificate product from [29]. As in *BuildingCalc/LighCalc* it is not possible to simulate the mullions, the properties of an equivalent frame placed only in the border of the window have to be calculated. These equivalent properties are presented in **Table 5.3**.

Table 5.3 - Properties of the equivalent frame for the test room façade

property	value
U-value [W/m^{2}K]	0.73
Frame width [m]	0.08
Linear thermal transmittance [W/mK]	0.056

5.1.3 Type of construction and furniture

It was assumed that the U-value of all the solutions in contact with the outside would be 0.1W/m^{2}K (for wall, roof and floor)
According to the assumptions previously mentioned this means an overall UA-value of 15.46W/K. This value takes into account the sum of transmission losses through the elements facing outside excluding windows. For simplifying reasons the linear transmittance losses through the thermal bridges were neglected.

In the *BuildingCalc* userguide [11] there are already some predefined classes and values for the heat capacity of buildings. It was assumed that the type of construction of the office is middle light (which means few heavy parts) which corresponds to a total heat capacity of 5.76x10^{7}J/K. This assumption takes into account that usually in landscaped office buildings the solutions for the floor and ceiling are false to allow the installations to be placed inside. Also the partitions are made of very light materials.

Additional heat capacity of the furniture was considered. Taking into account that there are 15 working places, that each one has a weight of 200kg and that the heat capacity of each kg is 1000J/K, the total contribution of the furniture is $3x10^6$J/K.

5.1.4 Systems

Six different systems were defined to simulate different periods of the year and distinct using conditions. This is one of the great advantages of *BuildingCalc/Lightcalc*, it allows to define different settings for different periods according to the correspondent requirements.
Thus, three systems were defined for the coldest months (December, January and February - weeks 1 to 9 and 10 to 53) and three systems for the other months (March, April, May, June, July, August, September, October and November – weeks 10 to 48).

The three systems for each season are: one for working hours, other for non-working hours during working days and another one for weekends.

Two different solutions were studied:

1) no mechanical cooling available (when there is need for cooling the cooling systems are activated in the following order: shading, venting and increased mechanical ventilation)
2) mechanical cooling available (when the previous solutions are not enough to set the indoor temperature to the cooling setpoint the mechanical cooling is activated)

The first solution is the more environmental friendly since no energy for cooling is used. However in most cases this solution is not enough to achieve the indoor comfort level required on [14] specially regarding south Europe countries like Portugal.

The office is equipped with a heating system with an incorporated heat exchanger (with an efficiency of 0.85)

The heating system and the mechanical cooling (when available) are only active during working hours.
According to [14] the heating setpoint will be 20ºC (for a cloth level of 1.0).
In [14] it is required a cooling setpoint of 26ºC (for a cloth level of 0.5) but 22ºC will be set (even if the cloth level needs to be higher). The objective is that the cooling will start before the indoor temperature reaches 26ºC. This is a way of decreasing the hours of overheating above 26ºC which is a measure of discomfort.
Only during working hours mechanical ventilation is active with an airchange rate of $0.9h^{-1}$ which corresponds to $0.8l/s.m^2$ (requirement for a category II very low-polluted landscaped office [14]).

During working hours no venting was set. This is to contemplate the fact that sometimes office buildings are placed in areas with noise. In this way, venting by opening windows can lead to high levels of noise inside the office which can interfere with workers concentration and efficiency. Thus the indoor air quality should be guaranteed without venting.
Outside the coldest months venting with a setpoint of 20ºC was set at night and during weekends. This is especially important during summer nights to cool down the office when the outdoor temperature is lower.

The internal loads during the working hours were assumed to be 100W per person and 50W per equipment which gives a total of 2250W (considering the 15 working places).

The shading system will be dynamically controlled. It will be automatically activated when the indoor temperature is higher than the cooling setpoint. According to the needs, different positions can be set for the shading system. For instance the systems with slats are activated in a way that the orientation of the slats is enough to block the direct sun (cut off position).

For thermal benefits it was assumed that the shading is completely activated during nights and weekends. The activation of the shading means extra-insulation for the window which is important during winter in order to reduce the heat losses through the window.

The lightning level is automatically controlled during the working hours. When the general indoor daylight is lower than 200lux the electrically lightning will be switched on immediately to reach that level. For working areas in landscaped office buildings, according to [14] the requirement is 500lux. *BuildingCalc/LightCalc* will also keep this level with the use of electrical lightning when needed.
For general lightning level the wattage of the system used is 4W/m^2, while for specific tasks it is 1W/m^2.

5.2 Different settings for Lisbon

The goal is that the building in Lisbon is as much as possible similar to the building in Copenhagen, so the performance of the different solar shading systems can be compared between North and South Europe countries.

Only some changes were made. The first one is regarding the U-value of the exterior solutions. The value assumed for Copenhagen, 0.1W/m^2K is extremely low for Lisbon, since the winter is not so severe in the south Europe countries. According to the Portuguese building code [16], the reference U-value for exterior solutions is 0.60W/m^2K for vertical elements and 0.45W/m^2K for horizontal elements (for Lisbon - climate area I2). Thus 0.4W/m2K was used for whole the exterior solutions. This means a new UA-value of 61.85W/K.

To avoid overheating during the winter months (December, January and February) there was a need to set venting outside the working hours (night and weekends) also during these months. However the cooling setpoint is 22ºC instead of 20ºC (which was set for the other months). A cooling setpoint of 20ºC for venting during night and weekends in winter would lead to an increase on the heating demand.

5.3 Location and weather files

Also the location and weather data files must be loaded in *BuildingCalc/LightCalc*.

The location data for Copenhagen and Lisbon are presented on **Table 5.4.**

Table 5.4 - Location of Copenhagen and Lisbon

	Portugal **Lisbon**	Denmark **Copenhagen**
Lattitude	38.72 ºN	55.4 ºN
Longitude	9.13 ºW	12.19 ºE
Time meridian	0 º	15 º

The weather data for Copenhagen is based on the Danish design reference year [9].
The weather data for Lisbon is based on the TRY, Test reference year [19].

6. Energy Performance and indoor comfort evaluation

6.1 Requirements and expected results

6.1.1 Energy frame

6.1.1.1 Denmark

According to the Danish Building code [2], the energy frame for office buildings is given by:

$$E_t = 95 + 2200/A \quad \left[kWh/m^2.year\right] \tag{6.1}$$

where A is the internal floor area in m^2.

E_t, in kWh/m^2, is the yearly maximum total energy consumption that an office building may have to be in accordance with the Danish building code and it is approximately $95kWh/m^2$ for large office buildings ($A=2200m^2$). However, for the nowadays purpose of saving energy a lower energy demand would be expected (at least half of the standard limit).

The total energy consumption of a building, E_t, includes the energy for heating, E_h, cooling, E_c, lightning, E_l, mechanical ventilation, E_{mv} and hot water, E_{hw}. According to [2] the energy demands for lightning and mechanical ventilation must be multiplied by the factor 2.5 since they refer to electrical energy. The heating and cooling systems were assumed to be district systems and, in this way, the correspondent heating and cooling demand do not need to be affected by the factor 2.5. All the equipment efficiencies were considered equal to the unit.

$$E_t = E_h + E_c + 2.5 \times E_l + 2.5 \times E_{mv} + E_{hw} \quad \left[kWh/m^2.year\right] \tag{6.2}$$

For the different solutions of solar shading systems only the energies for heating, cooling and lightning vary and their values are calculated by *BuildingCalc/LightCalc*.

The mechanical ventilation was set constant during the working hours and equal to the minimum required on the indoor environment standard [14], $0.9h^{-1}$. The energy demand for mechanical ventilation is given by:

$$2.5 \times E_{mv} = 2.5 \times \frac{n \times airchange\_rate \times V \times SEL}{A} \times \frac{1}{3600} \left[kWh/m^2.year\right] \tag{6.3}$$

where *n* is the number of hours in which the required mechanical ventilation is set, 2871h (working hours)[1]; *airchange_rate* is the required airchange rate for indoor air quality, $0.9h^{-1}$; *SEL* is the specific electrical power consumption for air transport, $2kJ/m^3$; *V* is the inner volume of the office room, $660m^3$; *A* is the floor area, $200m^2$; and *1/3600* is the factor to convert kJ to kWh.
In this way, the total energy demand for mechanical ventilation, multiplied by the factor 2.5, is $11.8kWh/m^2.year$.

Regarding hot water, the typical consumption for an office building is 100l per m^2 per year which corresponds to an energy consumption, E_{hw} of:

$$E_{hw} = \frac{100 \times c_w \times \Delta T}{3600000} \quad \left[kWh/m^2.year\right] \tag{6.4}$$

Where $100l/m^2.year$ is the standard hot water consumption for an office building as referred before; c_w is the specific heat capacity of the water, 4187J/kg.ºC; ΔT is the temperature increase needed for the production of hot water, 45ºC; and 1/3600000 is the factor to convert J to kWh.
Thus, the energy demand for hot water is $5.2kWh/m^2.year$.

The sum of the energy for mechanical ventilation and hot water is $17kWh/m^2.year$ and it is constant for all the different solutions for solar shading systems.
This means that to fulfil the Danish building code requirements the sum of energy for heating, cooling and lightning must be lower than $78kWh/m^2.year$ (95-17=78 $kWh/m^2.year$). However, for the nowadays need of saving energy at least half of this value should be expected (78/2=39 $kWh/m^2.year$).

6.1.1.2 Portugal

According to the Portuguese building code the maximum value for primary energy consumption for new office buildings is $35kgep/m^2.year$. This means a maximum of $121kWh/m^2.year$ considering that all the energy in the building comes from electricity which is the most critical case (for electricity - 0.290kgep/kWh). [16]

While the Danish building code [2] defines only a limit for the total energy consumption of the building allowing the designer to save energy in different fields, the Portuguese code [16] defines also limits for the different types of energy needed in a building. According to [16], Portugal is divided in different climatic zones and these limits depend on the location of the office building and

[1] 2871h is an output of BuildingCalc/LightCalc and it corresponds to 11 hours per day, 5 days per week during one whole year. It was assumed that the ventilation systems would be switched on one hour before the working hours and switched off one hour after the working hours. No holidays were assumed.

on its shape factor, *FF* (which is the ratio between the exterior envelopment of the building and the inner volume).
For the studied building (which has a shape form of 0.30) located in Lisbon (which corresponds to winter climatic zone *I1* and summer climatic zone *V2 south*), the maximum values for the different energy demands are presented in **Table 6.1**.

Table 6.1 - Maximum values for energy consumption calculated according to the Portuguese building code[16]

Type of energy*	Consumption Limit [kWh/m^2.year]
Heating	52
Cooling	32
Hot water	11

*no specific limits are defined for mechanical ventilation and lightning energy demands

As referred before (in chapter **6.1.1.1 Denmark** of this dissertation) the energy demand for mechanical ventilation and hot water is constant for the different solar shading systems and equal to 17kWh/m^2.year. In this way, this value can be subtracted to 121kWh/m^2.year and 104kWh/m^2.year can be obtained. This last value is the maximum total energy available for heating, cooling and lightning in order to fulfil the Portuguese requirements. In spite of being extremely high for nowadays concerning of saving energy, this is the standard requirement in Portugal.

6.1.2 Indoor comfort

BuildingCalc/LightCalc is able to calculate two different parameters that show the performance of the simulated building regarding the indoor comfort. These two parameters are the hours of overheating above a specified temperature and the PPD index.

According to the indoor environment standard [14], for a category II landscaped office building the working hours above 26ºC during one whole year should not be more than 108. At the same time daily, weekly and monthly criteria is set: for instance no more than 24min of overheating per day or 2 hours per week should occur. The objective of this is to keep a good level of comfort during all the working days of the year, avoiding for example summer days in which the temperature is always above 26ºC. During these days the concentration and the efficiency of the workers would be reduced.
However, only the yearly criteria will be checked since it is the one automatically calculated by *BuildingCalc/LightCalc*.

Also in accordance with [14], for a category II building, it is recommended that the PPD index is lower than 10%.

6.2 Characterization of the solar shading systems used

In **Table 6.2** it is presented the solar shading systems whose performances were evaluated in this dissertation as well as their geometrical (thickness, t), thermal (material conductivity, λ; material IR emissivity outdoor, IR ε_{out}; and material IR emissivity indoor, IR ε_{ind}) and integrated optical characteristics (solar transmittance, τ_S; solar reflectance, ρ_S; visual transmittance, τ_V, and visual reflectance,ρ_V).

Excluding the external venetian blinds (aluminium lamellas) and the glass lamellas the other solar shading systems were already in *WIS* database. The external venetian blinds were modelled as presented in chapter **8.2.2 Venetian blinds** of this dissertation and the glass lamellas as illustrated in **APPENDICES C** and **D**.

For the venetian blinds the letters w, c and p, define respectively the slat chord width, the crown height and the slat pitch as shown in **Figure 6.1**.

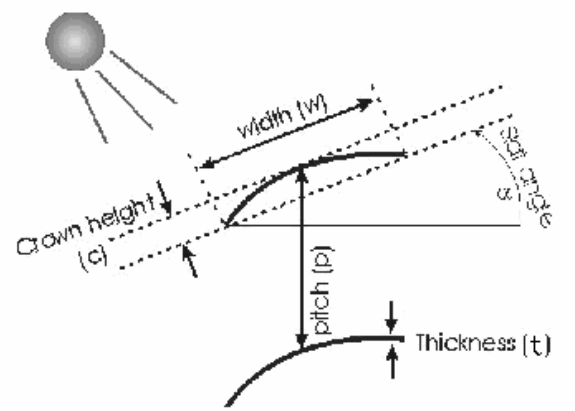

Figure 6.1 - Venetian blind geometry [41]

For the systems composed of slats (as the venetian blinds and the glass lamellas), the characteristics refer to the system completely activated (slat angle of 90º)

Table 6.2 - Properties of the solar shading systems whose performances were evaluated

				thermal properties			optical properties			
ID	**Position/Type** (Product name)	**Description**	**t [mm]**	**λ [W/mK]**	**IR ε_{out} [-]**	**IR ε_{ind} [-]**	**τ_S [-]**	**ρ_S [-]**	**τ_V [-]**	**ρ_V [-]**
A	**Internal Roller Blinds**	**(50mm air gap between the glazing and the shading)**								
1	Verosol Roller 818-000 UT light-grey	ultra transparent (OF=40%), f. metallic, b. light-grey	0.18	0.20	0.510	0.811	0.44	0.34	0.44	0.33
2	Verosol Roller 818-741 UT beige	ultra transparent (OF=40%), f. metallic, b. Beige	0.18	0.20	0.510	0.811	0.44	0.34	0.44	0.33
3	Verosol Roller 818-936 UT dark-grey	ultra transparent (OF=40%), f. metallic, b. dark-grey	0.18	0.20	0.510	0.811	0.20	0.35	0.33	0.29
4	Verosol Roller 875-000 BO light-grey	black-out (OF=0%), f. metallic, b. light-grey	0.18	0.20	0.285	0.807	0.04	0.68	0.04	0.67
5	Verosol Roller 875-936 BO dark-grey	black-out (OF=0%), f. metallic, b. dark-grey	0.18	0.20	0.285	0.807	0.02	0.68	0.02	0.67
6	Verosol Roller 816-000 T light-grey	transparent (OF=23%), f. metallic, b. light-grey	0.23	0.20	0.506	0.802	0.29	0.44	0.29	0.43
7	Verosol Roller 816-936 T dark-grey	transparent (OF=23%), f. metallic, b. dark-grey	0.23	0.20	0.506	0.802	0.28	0.44	0.27	0.43
8	Verosol Roller 312-000 HT dark-grey	half transparent (OF=2%), f. metallic, b. light-grey	0.18	0.20	0.342	0.767	0.06	0.66	0.05	0.64
9	Verosol Roller 312-936 HT dark-grey	half transparent (OF=2%), f. metallic, b. dark-grey	0.18	0.20	0.342	0.767	0.04	0.66	0.03	0.64
10	Verosol SilverScreen white ED01 HT	half transparent (OF=4%), f. metallic, b. white	0.50	0.15	0.160	0.830	0.06	0.74	0.06	0.73
11	Verosol SilverScreen black EB01 HT	half transparent (OF=4%), f. metallic, b. black	0.50	0.15	0.160	0.810	0.05	0.75	0.05	0.74
B	**Interpane Roller Blinds**	**(placed on the outer gap - 9mm distance from outer pane and 5mm distance from the middle pane)**								
12	Verosol Roller 818-000 UT light-grey	ultra transparent (OF=40%), f. metallic, b. light-grey	0.18	0.20	0.510	0.811	0.44	0.34	0.44	0.33
13	Verosol Roller 875-000 BO light-grey	black-out (OF=0%), f. metallic, b. light-grey	0.18	0.20	0.285	0.807	0.04	0.68	0.04	0.67
14	Verosol SilverScreen white ED01 HT	half transparent (OF=4%), f. metallic, b. white	0.50	0.15	0.160	0.830	0.06	0.74	0.06	0.73
15	Verosol SilverScreen black EB01 HT	half transparent (OF=4%), f. metallic, b. black	0.50	0.15	0.160	0.810	0.05	0.75	0.05	0.74
C	**External Roller Blinds**	**(50mm air gap between the glazing and the shading with free ventilation)**								
16	Verosol SilverScreen white ED01 HT	half transparent (OF=4%), f. metallic, b. white	0.50	0.15	0.160	0.830	0.06	0.74	0.06	0.73
17	Verosol SilverScreen black EB01 HT	half transparent (OF=4%), f. metallic, b. black	0.50	0.15	0.160	0.810	0.05	0.75	0.05	0.74
D	**Internal Venetian Blinds**	**(50mm air gap between the glazing and the shading)**								
18	Luxaflex venetian blind 8% Perforation 2053	w=25mm, c=0mm, p=20mm, grey metallic	0.22	100.00	0.670	0.670	0.06	0.40	0.06	0.40
19	Luxaflex venetian blind 8% Perforation 6127	w=25mm, c=0mm, p=20mm, black	0.22	100.00	0.640	0.640	0.06	0.05	0.06	0.04
20	Luxaflex venetian blind 8027	w=25mm, c=0mm, p=20mm, supermat grey	0.22	100.00	0.819	0.819	0.00	0.56	0.00	0.62
21	Luxaflex venetian blind High Mirror 4078	w=25mm, c=0mm, p=20mm, f. high mirror, b. grey stone	0.22	100.00	0.710	0.680	0.00	0.83	0.00	0.83
22	Luxaflex venetian blind Metallic 8081	w=25mm; c=0mm; p=20mm, metallic grey	0.22	100.00	0.392	0.392	0.00	0.69	0.00	0.66
23	Luxaflex venetian blind Thermostop 2383	w=25mm; c=0mm; p=20mm, white	0.22	100.00	0.800	0.260	0.00	0.70	0.00	0.78
E	**Interpane Venetian Blinds**	**(placed on the outer gap - 16mm distance from outer pane and 13mm distance from the middle pane)**								
24	Luxaflex venetian blind 8% Perfor 2053	w=16mm, c=0mm; p=12mm, grey metallic	0.22	100.00	0.670	0.670	0.06	0.40	0.06	0.40
25	Luxaflex venetian blind 8% Perfor 6127	w=16mm, c=0mm; p=12mm, black	0.22	100.00	0.640	0.640	0.06	0.05	0.06	0.04
26	Luxaflex venetian blind 8027	w=16mm, c=0mm; p=12mm, supermat grey	0.22	100.00	0.819	0.819	0.00	0.56	0.00	0.62
27	Luxaflex venetian blind High Mirror 4078	w=16mm, c=0mm; p=12mm, f. high mirror, b. grey stone	0.22	100.00	0.710	0.680	0.00	0.83	0.00	0.83
28	Luxaflex venetian blind Thermostop 2383	w=16mm, c=0mm; p=12mm, white	0.22	100.00	0.800	0.260	0.00	0.70	0.00	0.78
F	**External Venetian Blinds**	**(50mm air gap between the glazing and the shading with free ventilation) - integrated data based on Warema manufacture**								
29	Aluminium lamellas_60mm	w=60mm; c=5mm; p=42mm	0.50	150.00	0.800	0.800	0.00	0.40	0.00	0.40
30	Aluminium lamellas_80mm	w=80mm; c=5mm; p=42mm	0.50	150.00	0.800	0.800	0.00	0.40	0.00	0.40
31	Aluminium lamellas_100mm	w=100mm; c=10mm; p=92mm	0.50	150.00	0.800	0.800	0.00	0.40	0.00	0.40

Table 6.2 (Cont.) - Properties of the solar shading systems whose performances were evaluated

				thermal properties			optical properties			
ID	**Position/Type** (Product name)	**Description**	**t [mm]**	**λ [W/mK]**	**IR ε_{out} [-]**	**IR ε_{ind} [-]**	**τ_S [-]**	**ρ_S [-]**	**τ_V [-]**	**ρ_V [-]**
G	**External Glass Lamellas**	**(400mm air gap between the glass lamellas and the glazing with free ventilation) - spectral data from glass**								
32	SGG_Antelio Silver_500mm	hard coating on the outer surface	8.00	1.00	0.837	0.837	0.63	0.25	0.66	0.31
33	SGG_Antelio Clear_500mm	hard coating on the outer surface	8.00	1.00	0.837	0.837	0.50	0.26	0.45	0.32
34	SGG_Reflectasol Grey_500mm	hard coating on the outer surface	8.00	1.00	0.837	0.837	0.33	0.39	0.19	0.53
35	Glav_Stopsol Silverlight Green_500mm	hard coating on the outer surface	8.00	1.00	0.837	0.837	0.30	0.20	0.54	0.25
H	**Solar Control Glazings**	**(solar contral glass replacing the reference outer pane; when there is a coated surface, if nothing else is referred, it means that the coated surface is facing the air cavity)**								
36	Pilkington Artic Blue™	body tinted float glass	4.00	1.00	0.837	0.837	0.49	0.06	0.67	0.06
37	Pilkington Optifloat Clear™	body tinted float glass	4.00	1.00	0.837	0.837	0.82	0.08	0.90	0.08
38	Pilkington Optifloat Green™	body tinted float glass	4.00	1.00	0.837	0.837	0.56	0.06	0.80	0.07
39	Pilkington Suncoool Brilliant 66-33™	soft low-e coating + high visible light transmittance	4.00	1.00	0.837	0.030	0.39	0.34	0.74	0.13
40	Pilkington Suncool HP Silver 50-30™	soft low-e coating + high visible light transmittance	6.00	1.00	0.837	0.034	0.32	0.43	0.54	0.36
41	SSG Antelio Silver	hard coating (applied on a clear glass)	6.00	1.00	0.837	0.837	0.63	0.21	0.66	0.29
42	SSG Antelio Silver_outer surface coated	hard coating (applied on a clear glass)	6.00	1.00	0.837	0.837	0.63	0.25	0.66	0.31
43	SSG Antelio Esmeralda	hard coating (applied on a body tinted glass)	6.00	1.00	0.837	0.837	0.50	0.19	0.45	0.26
44	SSG Antelio Esmeralda_outer surface coated	hard coating (applied on a body tinted glass)	6.00	1.00	0.837	0.837	0.50	0.26	0.45	0.32
45	SSG Reflectasol Green	hard coating	6.00	1.00	0.837	0.837	0.19	0.16	0.26	0.32
46	SSG Cool-Lite KS147	soft coating	6.00	1.00	0.837	0.036	0.29	0.43	0.47	0.42
I	**Combinations**	**(combination of the previous solutions)**								
47	PilkingArticBlue+IntVerosolSilverScreenED01	H36 + A10								
48	PilkingArtic Blue+ExtVerosolSilverScreenED01	H36 + C16								
49	PilkingArticBlue+Int LuxaflexVenBlind4078	H36 + D21								
50	PilkingArticBlue+ExtAlumLamellas_60mm	H36 + F29								
51	SGGReflectGreen+IntVerosolRollerED01	H45 + A10								
52	SGGReflectGreen+ExtVerosolRoller ED01	H45 + C16								
53	SGGReflectGreen+IntLuxaflexVenBlind4078	H45 + D21								
54	SGGReflectGreen+ExtAlumLamellas_60mm	H45 + F29								

these solutions result from combinations of the previous ones

6.3 Results

In **Table 6.3** and **Table 6.4** the performance of the landscaped office room is presented for the reference glazing and for the combination of the reference glazing with the different solar shading systems. **Table 6.3** refers to Copenhagen and **Table 6.4** to Lisbon. The results painted as grey are the ones that do not fulfil the standards.
The tables are organized in three distinct groups of columns:

System properties - where the performances of the reference glazing and of the combination of different solar shading systems with the reference glazing are presented in terms of thermal transmittance coefficient (U-value), solar heat gain coefficient (g-value), solar shading coefficient (SSC), visual transmittance (τ_V), visual shading coefficient (VSC) and rendering index (Ra). These values were obtained in *WIS* and refer to the solar shading systems completely activated.

Without mechanical cooling - the values presented in these columns were calculated in *BuildingCalc/LightCalc*. They show the performance of the landscaped office room (previously described) for the reference glazing and also for the combination of different solar shading systems with the reference glazing. No mechanical cooling was set.
The performance of the office building with the different solar shading systems is presented in terms of energy demand for heating and lightning, total energy demand, hours of overheating and PPD index.

With mechanical cooling - these columns also refer to the performance of the office room with the different solutions for the solar shading systems in combination with the reference glazing. In this case mechanical cooling was applied to eliminate completely the hours of overheating and the energy demand for it is also presented (as 22ºC is the setpoint defined for cooling, no hours above this temperature will be registered).

Notes:

The simulations for Denmark were done using a version of *BuildingCalc/LightCalc* that had an error. Venting during night and weekends was only occurring when the outdoor temperature was lower than the cooling setpoint, even if the indoor temperature was higher than the outdoor temperature. This could lead to more hours of overheating than in a real situation. However the influence of this mistake was tested in the updated version of *BuildingCalc/LightCalc* and for most cases only a reduction of approximately 10hours above 26ºC was detected. This difference is insignificant and does not have an important influence on the cooling demand for the building when mechanical cooling is activated.
For Portugal the updated version of *BuildingCalc/LightCalc* was used.

While for Portugal the hours of overheating above 22ºC, 24ºC and 26ºC are presented, for Denmark only hours above 26ºC are presented. The reason is that the simulations for Denmark were performed using a *BuildingCalc/LightCalc* runtime version (version that does not need MatLab to run) where the option “export results” is not implemented. In this way to get the hours above 22ºC and 24ºC the simulations would have to be all repeated. Besides being time consuming, this procedure was not find relevant since the indoor standard requirement only refers to overheating as hours above 26ºC.

Table 6.3 - Energy and indoor comfort performance of the landscaped office room in **Copenhagen** for the reference glazing and for the combination of the reference glazing with the different solar shading systems

		system properties[1]						without mechanical cooling					with mechanical cooling[2]				
ID	**Position/Type** (Product name)	**U-value** [W/m²K]	**g-value** [-]	**SSC** [-]	**τ_v** [-]	**VSC** [-]	**Ra** [%]	**heating** [kWh/m²]	**lightning** [kWh/m²]	**total**[3] [kWh/m²]	**T>26ºC** [h]	**PPD** [%]	**heating** [kWh/m²]	**cooling** [kWh/m²]	**lightning** [kWh/m²]	**total**[4] [kWh/m²]	**PPD** [%]
REF	**Reference Glazing**	0.68	0.49	1.00	0.68	1.00	96	0.55	3.21	8.56	260	12	0.61	22.58	3.21	31.20	7
A	**Internal Roller Blinds**																
1	Verosol Roller 818-000 UT light-grey	0.60	0.40	0.82	0.33	0.49	95	0.50	3.78	9.94	182	11	0.54	17.83	3.62	27.42	7
2	Verosol Roller 818-741 UT beige	0.60	0.40	0.82	0.35	0.51	95	0.50	3.78	9.94	182	11	0.54	17.83	3.62	27.42	7
3	Verosol Roller 818-936 UT dark-grey	0.60	0.40	0.82	0.33	0.49	95	0.47	3.82	10.01	182	11	0.51	17.89	3.66	27.53	7
4	Verosol Roller 875-000 BO light-grey	0.54	0.27	0.55	0.03	0.04	94	0.44	8.72	22.24	131	10	0.44	15.02	8.05	35.59	8
5	Verosol Roller 875-936 BO dark-grey	0.54	0.27	0.55	0.01	0.01	93	0.44	8.74	22.27	131	10	0.44	14.98	8.06	35.57	8
6	Verosol Roller 816-000 T light-grey	0.59	0.36	0.73	0.23	0.34	94	0.48	4.58	11.93	162	10	0.50	16.50	4.32	27.78	8
7	Verosol Roller 816-936 T dark-grey	0.59	0.36	0.73	0.21	0.31	95	0.48	4.60	11.98	162	10	0.50	16.50	4.33	27.82	8
8	Verosol Roller 312-000 HT dark-grey	0.55	0.28	0.57	0.04	0.06	95	0.45	8.20	20.95	133	10	0.46	14.94	7.45	34.02	8
9	Verosol Roller 312-936 HT dark-grey	0.55	0.28	0.57	0.02	0.03	94	0.45	8.24	21.05	134	10	0.46	15.05	7.61	34.52	8
10	Verosol SilverScreen white ED01 HT	0.51	0.25	0.51	0.05	0.07	94	0.41	7.15	18.27	101	9	0.41	12.47	6.69	29.59	8
11	Verosol SilverScreen black EB01 HT	0.51	0.25	0.51	0.04	0.06	94	0.41	7.28	18.61	101	9	0.41	12.38	6.82	29.83	8
B	**Interpane Roller Blinds**																
12	Verosol Roller 818-000 UT light-grey	0.72	0.30	0.61	0.32	0.47	95	0.65	3.71	9.93	103	9	0.66	12.28	3.61	21.94	8
13	Verosol Roller 875-000 BO light-grey	0.71	0.11	0.22	0.03	0.04	94	0.79	7.92	20.59	17	8	0.79	6.38	7.61	26.19	8
14	Verosol SilverScreen white ED01 HT	0.70	0.10	0.20	0.05	0.07	94	0.80	6.63	17.38	2	8	0.80	5.40	6.41	22.21	8
15	Verosol SilverScreen black EB01 HT	0.70	0.10	0.20	0.04	0.06	95	0.81	6.68	17.51	0	8	0.81	5.11	6.44	22.02	8
C	**External Roller Blinds**																
16	Verosol SilverScreen white ED01 HT	0.62	0.04	0.08	0.01	0.01	94	0.77	6.33	16.58	0	8	0.77	3.24	6.18	19.46	8
17	Verosol SilverScreen black EB01 HT	0.62	0.03	0.06	0.03	0.04	95	0.78	6.31	16.56	0	8	0.78	2.97	6.17	19.18	8
D	**Internal Venetian Blinds**																
18	Luxaflex venetian blind 8% Perforation 2053	0.58	0.36	0.73	0.04	0.06	95	0.43	4.54	11.78	229	12	0.47	20.85	4.30	32.07	7
19	Luxaflex venetian blind 8% Perforation 6127	0.58	0.44	0.90	0.04	0.06	96	0.42	4.64	12.01	252	12	0.47	22.37	4.34	33.68	7
20	Luxaflex venetian blind 8027	0.60	0.30	0.61	0.00	0.00	78	0.46	4.51	11.72	217	12	0.50	20.06	4.29	31.27	7
21	Luxaflex venetian blind High Mirror 4078	0.58	0.23	0.47	0.00	0.00	90	0.46	4.51	11.72	214	12	0.49	19.79	4.30	31.02	7
22	Luxaflex venetian blind Metallic 8081	0.54	0.27	0.55	0.00	0.00	94	0.39	4.49	11.62	213	11	0.42	19.72	4.28	30.83	7
23	Luxaflex venetian blind Thermostop 2383	0.56	0.24	0.49	0.00	0.00	83	0.42	4.49	11.63	207	11	0.45	19.48	4.28	30.61	7

[1] For the systems that have orientable slats (like venetian blinds and glass lamellas) the properties refer to the system completely activated (90º slat position)
[2] The setpoint for cooling is 22ºC, so when the mechanical cooling is activated there are no hours above 22ºC
[3] Total energy demand = heating demand + 2.5 lightning demand
[4] Total energy demand = heating demand + cooling demand + 2.5 lightning demand

Table 6.3 (Cont.1) - Energy and indoor comfort performance of the landscaped office room in **Copenhagen** for the reference glazing and for the combination of the reference glazing with the different solar shading systems

		system properties[1]						without mechanical cooling					with mechanical cooling[2]				
ID	**Position/Type** (Product name)	**U-value** [W/m²K]	**g-value** [-]	**SSC** [-]	τ_v [-]	**VSC** [-]	**Ra** [%]	**heating** [kWh/m²]	**lightning** [kWh/m²]	**total**[3] [kWh/m²]	**T>26ºC** [h]	**PPD** [%]	**heating** [kWh/m²]	**cooling** [kWh/m²]	**lightning** [kWh/m²]	**total**[4] [kWh/m²]	**PPD** [%]
E	**Interpane Venetian Blinds**																
24	Luxaflex venetian blind 8% Perfor 2053	0.57	0.17	0.35	0.02	0.03	95	0.47	4.34	11.31	93	9	0.47	11.65	4.22	22.66	8
25	Luxaflex venetian blind 8% Perfor 6127	0.57	0.23	0.47	0.02	0.03	96	0.47	4.35	11.34	94	9	0.47	11.80	4.23	22.83	8
26	Luxaflex venetian blind 8027	0.58	0.12	0.24	0.00	0.00	76	0.49	4.33	11.31	93	9	0.49	11.72	4.21	22.74	8
27	Luxaflex venetian blind High Mirror 4078	0.57	0.07	0.14	0.00	0.00	91	0.48	4.32	11.28	89	9	0.48	11.35	4.21	22.34	8
28	Luxaflex venetian blind Thermostop 2383	0.53	0.09	0.18	0.00	0.00	76	0.42	4.33	11.23	93	9	0.42	11.59	4.21	22.54	8
F	**External Venetian Blinds**																
29	Aluminium lamellas_60mm	0.62	0.01	0.02	0.00	0.00	0	0.67	4.14	11.00	0	8	0.67	4.00	4.09	14.88	8
30	Aluminium lamellas_80mm	0.62	0.01	0.02	0.00	0.00	0	0.67	4.06	10.82	0	8	0.67	4.60	4.02	15.30	8
31	Aluminium lamellas_100mm	0.62	0.01	0.02	0.00	0.00	0	0.67	4.06	10.82	0	8	0.67	4.66	4.02	15.38	8
G	**External Glass Lamellas**																
32	SGG_Antelio Silver_500mm	0.63	0.28	0.57	0.20	0.29	94	0.84	4.10	11.09	74	9	0.85	9.12	4.05	20.09	8
33	SGG_Antelio Clear_500mm	0.63	0.21	0.43	0.15	0.22	95	0.99	4.30	11.72	35	9	0.99	6.65	4.25	18.26	8
34	SGG_Reflectasol Grey_500mm	0.63	0.12	0.24	0.08	0.12	82	1.07	4.38	12.00	23	9	1.07	5.62	4.34	17.54	8
35	Glav_Stopsol Silverlight Green_500mm	0.63	0.17	0.35	0.13	0.19	83	1.08	4.21	11.59	18	9	1.08	5.31	4.16	16.77	8
H	**Solar Control Glazings**																
36	Pilkington Artic Blue™	0.96	0.38	0.78	0.52	0.76	85	1.91	3.69	11.12	106	10	1.92	12.31	3.69	23.44	8
37	Pilkington Optifloat Clear™	0.96	0.56	1.14	0.71	1.04	96	1.03	3.14	8.87	337	14	1.17	27.04	3.14	36.05	7
38	Pilkington Optifloat Green™	0.96	0.42	0.86	0.63	0.93	90	1.65	3.33	9.96	151	11	1.68	15.49	3.33	25.48	8
39	Pilkington Suncoool Brilliant 66-33™	0.65	0.35	0.71	0.59	0.87	94	0.84	3.46	9.49	105	10	0.85	12.06	3.46	21.55	8
40	Pilkington Suncool HP Silver 50-30™	0.66	0.29	0.59	0.43	0.63	93	1.07	3.94	10.90	82	9	1.07	9.58	3.94	20.48	8
41	SSG Antelio Silver	0.96	0.43	0.88	0.54	0.79	97	1.47	3.55	10.35	191	11	1.51	18.05	3.55	28.43	8
42	SSG Antelio Silver_outer surface coated	0.96	0.43	0.88	0.53	0.78	97	1.50	3.56	10.40	184	11	1.54	17.64	3.56	28.08	8
43	SSG Antelio Esmeralda	0.96	0.28	0.57	0.43	0.63	90	2.58	3.99	12.55	56	9	2.58	7.61	3.99	20.16	9
44	SSG Antelio Esmeralda_outer surface coated	0.96	0.27	0.55	0.43	0.63	90	2.69	4.03	12.76	45	9	2.69	7.05	4.03	19.81	9
45	SSG Reflectasol Green	0.96	0.17	0.35	0.21	0.31	88	3.78	5.65	17.91	0	9	3.78	3.97	5.65	21.88	9
46	SSG Cool-Lite KS147	0.66	0.26	0.53	0.39	0.57	95	1.15	4.12	11.44	74	9	1.15	8.69	4.12	20.13	8

[1] For the systems that have orientable slats (like venetian blinds and glass lamellas) the properties refer to the system completely activated (90º slat position)
[2] The setpoint for cooling is 22ºC, so when the mechanical cooling is activated there are no hours above 22ºC
[3] Total energy demand = heating demand + 2.5 lightning demand
[4] Total energy demand = heating demand + cooling demand + 2.5 lightning demand

Table 6.3 (Cont.2) - Energy and indoor comfort performance of the landscaped office room in **Copenhagen** for the reference glazing and for the combination of the reference glazing with the different solar shading systems

		system properties[1]						without mechanical cooling					with mechanical cooling[2]				
ID	**Position/Type** (Product name)	**U-value** [W/m^{2}K]	**g-value** [-]	**SSC** [-]	**τ_v** [-]	**VSC** [-]	**Ra** [%]	**heating** [kWh/m^2]	**lightning** [kWh/m^2]	**total**[3] [kWh/m^2]	**T>26°C** [h]	**PPD** [%]	**heating** [kWh/m^2]	**cooling** [kWh/m^2]	**lightning** [kWh/m^2]	**total**[4] [kWh/m^2]	**PPD** [%]
I	**Combinations**																
47	PilkingArticBlue+IntVerosolSilverScreenED01	0.66	0.18	0.37	0.04	0.06	83	0.28	7.16	18.18	31	8	0.28	8.28	6.85	25.66	8
48	PilkingArtic Blue+ExtVerosolSilverScreenED01	0.85	0.03	0.06	0.03	0.04	82	0.72	6.62	17.26	0	8	0.72	3.07	6.47	19.95	8
49	PilkingArticBlue+Int LuxaflexVenBlind4078	0.77	0.16	0.33	0.00	0.00	79	0.48	4.72	12.27	89	9	0.49	12.55	4.55	24.40	8
50	PilkingArticBlue+ExtAlumLamellas_60mm	0.86	0.01	0.02	0.00	0.00	0	0.61	4.33	11.44	0	8	0.61	3.76	4.28	15.07	8
51	SGGReflectGreen+IntVerosolRollerED01	0.66	0.10	0.20	0.02	0.03	89	0.30	7.40	18.80	0	8	0.30	5.34	7.16	23.54	8
52	SGGReflectGreen+ExtVerosolRoller ED01	0.85	0.02	0.04	0.00	0.00	88	0.68	6.99	18.16	0	8	0.68	3.00	6.83	20.74	8
53	SGGReflectGreen+IntLuxaflexVenBlind4078	0.77	0.09	0.18	0.00	0.00	87	0.40	5.72	14.70	5	8	0.40	6.03	5.57	20.34	8
54	SGGReflectGreen+ExtAlumLamellas_60mm	0.85	0.01	0.02	0.00	0.00	0	0.62	5.40	14.11	0	8	0.62	3.32	5.30	17.17	8

[1] For the systems that have orientable slats (like venetian blinds and glass lamellas) the properties refer to the system completely activated (90º slat position)
[2] The setpoint for cooling is 22ºC, so when the mechanical cooling is activated there are no hours above 22ºC
[3] Total energy demand = heating demand + 2.5 lightning demand
[4] Total energy demand = heating demand + cooling demand + 2.5 lightning demand

Table 6.4 - Energy and indoor comfort performance of the landscaped office room in **Lisbon** for the reference glazing and for the combination of the reference glazing with the different solar shading systems

		system properties[1]						without mechanical cooling							with mechanical cooling[2]				
ID	Position/Type (Product name)	U-value	g-value	SSC	τ_v	VSC	Ra	heating	lightning	total[3]	T>22ºC	T>24º	T>26ºC	PPD	heating	cooling	lightning	total[4]	PPD
		[W/m²K]	[-]	[-]	[-]	[-]	[%]	[kWh/m²]	[kWh/m²]	[kWh/m²]	[h]	[h]	[h]	[%]	[kWh/m²]	[kWh/m²]	[kWh/m²]	[kWh/m²]	[%]
REF	**Reference Glazing**	0.68	0.49	1.00	0.68	1.00	96	0.00	1.54	3.84	2177	1554	1009	28	0.00	61.27	1.54	65.10	5
A	**Internal Roller Blinds**																		
1	Verosol Roller 818-000 UT light-grey	0.60	0.40	0.82	0.33	0.49	95	0.02	2.90	7.25	1965	1220	667	20	0.02	47.65	2.65	54.29	5
4	Verosol Roller 875-000 BO light-grey	0.54	0.27	0.55	0.03	0.04	94	0.02	11.96	29.92	1934	1114	544	16	0.02	41.48	10.62	68.05	6
10	Verosol SilverScreen white ED01 HT	0.51	0.25	0.51	0.05	0.07	94	0.02	9.53	23.84	1882	963	451	14	0.02	36.50	8.43	57.59	6
11	Verosol SilverScreen black EB01 HT	0.51	0.25	0.51	0.04	0.06	94	0.02	9.81	24.53	1879	953	447	14	0.02	36.30	8.68	58.02	6
B	**Interpane Roller Blinds**																		
12	Verosol Roller 818-000 UT light-grey	0.72	0.30	0.61	0.32	0.47	95	0.02	2.86	7.16	1863	961	454	15	0.03	37.06	2.64	43.67	5
13	Verosol Roller 875-000 BO light-grey	0.71	0.11	0.22	0.03	0.04	94	0.04	11.09	27.75	1566	558	193	10	0.04	22.84	10.04	47.98	6
14	Verosol SilverScreen white ED01 HT	0.70	0.10	0.20	0.05	0.07	94	0.04	8.83	22.12	1431	504	168	9	0.04	20.50	8.03	40.60	6
15	Verosol SilverScreen black EB01 HT	0.70	0.10	0.20	0.04	0.06	95	0.05	8.90	22.30	1417	483	161	9	0.04	19.70	8.11	40.01	6
C	**External Roller Blinds**																		
16	Verosol SilverScreen white ED01 HT	0.62	0.04	0.08	0.01	0.01	94	0.08	8.17	20.51	1106	325	108	8	0.08	14.57	7.65	33.78	6
17	Verosol SilverScreen black EB01 HT	0.62	0.03	0.06	0.03	0.04	95	0.09	8.15	20.45	1083	290	101	8	0.09	13.75	7.67	33.00	6
D	**Internal Venetian Blinds**																		
18	Luxaflex venetian blind 8% Perforation 2053	0.58	0.36	0.73	0.04	0.06	95	0.01	4.47	11.19	2008	1357	800	23	0.02	53.42	3.86	63.08	5
19	Luxaflex venetian blind 8% Perforation 6127	0.58	0.44	0.90	0.04	0.06	96	0.01	4.55	11.39	2030	1415	856	24	0.02	56.02	3.91	65.79	5
20	Luxaflex venetian blind 8027	0.60	0.30	0.61	0.00	0.00	78	0.01	4.44	11.11	1997	1330	773	22	0.02	52.04	3.83	61.63	5
21	Luxaflex venetian blind High Mirror 4078	0.58	0.23	0.47	0.00	0.00	90	0.01	4.45	11.14	1994	1325	763	22	0.02	51.64	3.85	61.26	5
E	**Interpane Venetian Blinds**																		
24	Luxaflex venetian blind 8% Perfor 2053	0.57	0.17	0.35	0.02	0.03	95	0.02	4.24	10.60	1872	947	442	14	0.02	35.69	3.73	45.02	6
25	Luxaflex venetian blind 8% Perfor 6127	0.57	0.23	0.47	0.02	0.03	96	0.02	4.26	10.67	1871	948	449	14	0.02	35.96	3.75	45.36	6
27	Luxaflex venetian blind High Mirror 4078	0.57	0.07	0.14	0.00	0.00	91	0.02	4.22	10.57	1853	917	431	14	0.02	35.07	3.73	44.40	6
28	Luxaflex venetian blind Thermostop 2383	0.53	0.09	0.18	0.00	0.00	76	0.02	4.23	10.58	1866	939	440	14	0.02	35.56	3.72	44.87	6
					0.00	0.00													
F	**External Venetian Blinds**																		
29	Aluminium lamellas_60mm	0.62	0.01	0.02	0.00	0.00	0	0.03	3.87	9.71	1321	415	136	9	0.04	17.43	3.56	26.35	6
30	Aluminium lamellas_80mm	0.62	0.01	0.02	0.00	0.00	0	0.03	3.79	9.49	1352	472	156	9	0.03	18.80	3.45	27.45	6
31	Aluminium lamellas_100mm	0.62	0.01	0.02	0.00	0.00	0	0.03	3.79	9.49	1356	475	158	9	0.03	18.95	3.45	27.59	6

[1] For the systems that have orientable slats (like venetian blinds and glass lamellas) the properties refer to the system completely activated (90º slat position)

[2] The setpoint for cooling is 22ºC, so when the mechanical cooling is activated there are no hours above 22ºC

[3] Total energy demand = heating demand + 2.5 lightning demand

[4] Total energy demand = heating demand + cooling demand + 2.5 lightning demand

Table 6.4 (Cont.) - Energy and indoor comfort performance of the landscaped office room in **Lisbon** for the reference glazing and for the combination of the reference glazing with the different solar shading systems

		system properties[1]						without mechanical cooling							with mechanical cooling[2]				
ID	**Position/Type** (Product name)	U-value [W/m²K]	g-value [-]	SSC [-]	τ_v [-]	VSC [-]	Ra [%]	heating [kWh/m²]	lightning [kWh/m²]	total[3] [kWh/m²]	T>22ºC [h]	T>24º [h]	T>26ºC [h]	PPD [%]	heating [kWh/m²]	cooling [kWh/m²]	lightning [kWh/m²]	total[4] [kWh/m²]	PPD [%]
G	**External Glass Lamellas**																		
32	SGG_Antelio Silver_500mm	0.63	0.28	0.57	0.20	0.29	94	0.04	3.55	8.91	1694	859	392	13	0.04	31.21	3.23	39.33	6
33	SGG_Antelio Clear_500mm	0.63	0.21	0.43	0.15	0.22	95	0.06	3.76	9.46	1544	666	273	11	0.06	24.73	3.45	33.40	6
34	SGG_Reflectasol Grey_500mm	0.63	0.12	0.24	0.08	0.12	82	0.07	3.81	9.58	1423	586	238	11	0.07	21.89	3.51	30.73	6
35	Glav_Stopsol Silverlight Green_500mm	0.63	0.17	0.35	0.13	0.19	83	0.08	3.62	9.11	1421	577	229	11	0.08	21.50	3.34	29.91	6
H	**Solar Control Glazings**																		
36	Pilkington Artic Blue™	0.68	0.49	1.00	0.52	0.76	96	0.06	1.95	4.93	1174	991	479	15	0.06	37.57	1.95	42.50	6
40	Pilkington Suncool HP Silver 50-30™	0.65	0.35	0.71	0.43	0.63	94	0.04	2.15	5.42	1705	858	398	14	0.05	31.88	2.15	37.30	6
41	SSG Antelio Silver	0.66	0.29	0.59	0.54	0.79	93	0.03	1.80	4.52	1940	1228	689	13	0.04	48.84	1.80	53.36	6
43	SSG Antelio Esmeralda	0.96	0.43	0.88	0.43	0.63	97	0.11	2.24	5.71	1551	733	323	12	0.13	27.27	2.24	33.00	6
45	SSG Reflectasol Green	0.96	0.27	0.55	0.21	0.31	90	0.33	3.80	9.82	1147	458	159	10	0.34	17.31	3.80	27.13	7
46	SSG Cool-Lite KS147	0.96	0.17	0.35	0.39	0.57	88	0.05	2.30	5.80	1647	807	374	13	0.05	29.92	2.30	35.72	6
I	**Combinations**																		
47	PilkingArticBlue+IntVerosolSilverScreenED01	0.66	0.18	0.37	0.04	0.06	83	0.02	9.70	24.27	1727	676	275	11	0.03	27.58	8.71	49.36	6
48	PilkingArtic Blue+ExtVerosolSilverScreenED01	0.85	0.03	0.06	0.03	0.04	82	0.08	8.63	21.65	1094	306	107	8	0.08	14.27	8.13	34.67	6
49	PilkingArticBlue+Int LuxaflexVenBlind4078	0.77	0.16	0.33	0.00	0.00	79	0.02	5.03	12.59	1874	988	467	15	0.02	37.79	4.43	48.87	5
50	PilkingArticBlue+ExtAlumLamellas_60mm	0.86	0.01	0.02	0.00	0.00	0	0.04	4.31	10.80	1213	390	131	8	0.04	16.71	3.99	26.71	5
51	SGGReflectGreen+IntVerosolRollerED01	0.66	0.10	0.20	0.02	0.03	89	0.03	10.17	25.44	1457	485	159	9	0.03	20.14	9.29	43.38	6
52	SGGReflectGreen+ExtVerosolRoller ED01	0.85	0.02	0.04	0.00	0.00	88	0.08	9.37	23.49	1090	293	103	8	0.08	13.99	8.83	36.13	6
53	SGGReflectGreen+IntLuxaflexVenBlind4078	0.77	0.09	0.18	0.00	0.00	87	0.03	7.44	18.61	1537	564	202	10	0.03	23.02	6.71	39.82	6
54	SGGReflectGreen+ExtAlumLamellas_60mm	0.85	0.01	0.02	0.00	0.00	0	0.06	6.78	16.99	1153	357	117	8	0.06	15.60	6.30	31.39	6

[1] For the systems that have orientable slats (like venetian blinds and glass lamellas) the properties refer to the system completely activated (90º slat position)

[2] The setpoint for cooling is 22ºC, so when the mechanical cooling is activated there are no hours above 22ºC

[3] Total energy demand = heating demand + 2.5 lightning demand

[4] Total energy demand = heating demand + cooling demand + 2.5 lightning demand

In **Figure 6.2** it is presented the solar shading coefficients for the different types of solar shading systems when compared to the reference glazing. For the reference glazing the shading coefficient is equal to unit. As expected the external shading systems have higher performance controlling the solar gains.

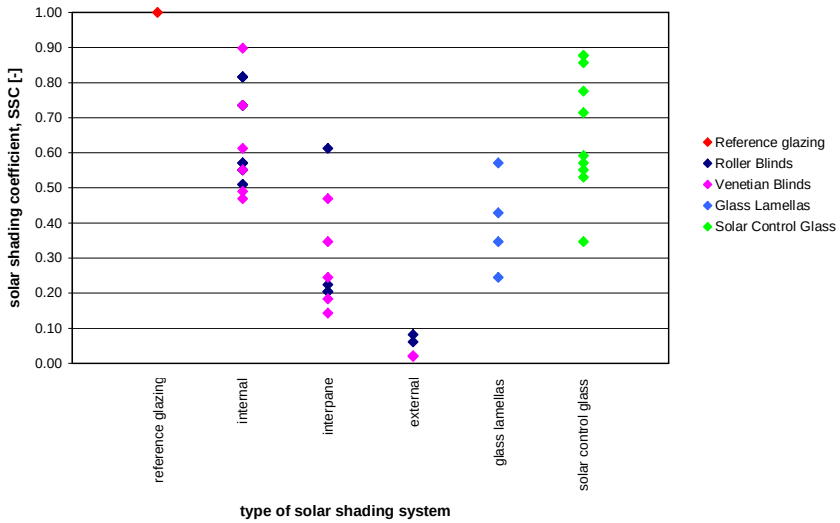

Figure 6.2 - Solar shading coefficients for the different solar shading systems comparing to the reference glazing

6.4 Discussion of the Results

6.4.1 Copenhagen

6.4.1.1 The reference system

Looking at the results for the energy performance of the landscaped office building (in Copenhagen) with the reference glazing it can be concluded that it is a relative high performance building.

The heating demand is extremely low, 0.55 kWh/m^2.year (for the case without mechanical cooling) which is due to the very good thermal insulation of the building envelope (very low U-values: 0.1W/m^2.K for exterior wall, roof and ground; and 0.68W/m^{2}K for the window) and also to the very high efficiency of the heat exchanger (0.85).

However, the building with the reference glazing and without mechanical cooling has some problems of indoor comfort. The number of overheating hours above 26ºC during one whole year is 206 which is higher than the standard requirement - 108 hours. Also the PPD index is 12% and it should be lower than 10%.

These indoor comfort problems can be easily solved with an air-conditioning system which leads to a yearly cooling demand of 23kWh/m^2. In this case the heating demand increases slightly, but the sum of heating, cooling and lightning demands is 31kWh/m^2.year which is still less than half of the

standard requirement calculated before (78kWh/m^2.year). Thus, with air-conditioning system the building fulfils the energy and indoor comfort requirements.

6.4.1.2 The different solar shading systems

In spite of being already in accordance with the standard requirement, different solar shading systems were added to the reference glazing. With this procedure the goal was to check if when using a solar shading system it is possible to fulfil the indoor comfort requirements without using mechanical cooling. And if not how well the shading systems perform reducing the cooling demand.

As presented in the table of results for Copenhagen (**Table 6.3**) most of the internal solutions for solar shading systems (roller blinds and venetian blinds) are not enough to accomplish the standard indoor comfort requirements without the use of an air-conditioning system. However these shading systems can slightly reduce the cooling demand.
Some special attention should be paid to the lightning demand. While reducing the solar gains and consequently the cooling demand, some solar shading systems also reduce the indoor daylight increasing in this way the need for electrical lightning. Sometimes the electrical lightning demand increases more than the cooling demand decreases, and the total energy demand is higher with the use of solar shading system than without it (this happens in cases A4, A5, A8, A9).

Regarding the interpane and external solar shading systems (roller blinds and venetian blinds) they are enough to, without the use of mechanical cooling system, accomplish the standard indoor comfort requirements.
However if better indoor conditions are desired an air-conditioning system may be used to completely eliminate the hours in which the temperature is above 22ºC (it is important to remember that this means a higher total energy consumption). In this case, even with an increase on electrical lightning demand caused by the shading system, the reduction on the cooling demand is such that total energy demand decreases: comparing to the reference glazing, a reduction to approximately 2/3 of the total energy demand can be achieved with the use of interpane or external roller blinds. The interpane venetian blinds can also reduce to 2/3 the total energy demand while the external venetian blinds can reduced it to 1/2.

With external glass lamellas it is also possible to fulfil the standard indoor requirements without the use of mechanical cooling. Once again if better levels of indoor environment are desired the mechanical system may be used. In this case, comparing to the solution with the reference glazing, the total amount of energy demand can be reduced to between 1/2 and 2/3 depending on the type of glass that composes the glass lamellas.

As it was expected, the electrical lightning demand is lower when using systems composed of slats than for instance roller blinds (specially the ones with very low openness factors). When the slat systems are activated to block the direct sun in order to avoid overheating the daylight can still

enter the room through the space between the slats. The same does not happen with the roller blinds.
It would be expected that the electrical lightning demand of the office room when using glass lamellas systems was lower than the one when using, for instance, external venetian blinds. However, when comparing both electrical lightning demands they are very similar. This is mainly due to the following difference between the two systems: while the external venetian blinds can be completely retracted during overcast days, the same does not happen with the glass lamellas, they are permanently in front of the façade and can only be tilted.

Concerning the solar control glasses not all the solutions simulated allow the accomplishment of the standard indoor requirements without the use of mechanical cooling.
As it was expected,when a solar control glass replaces the reference outer pane which was a low-e coating glass (Pilkington Optitherm SN4), the heating demand increases slightly.
The need for electrical lightning varies depending on how transparent to light the glass is.
When compared to the reference glazing, the total energy demand for some solar control glasses combined with mechanical cooling can be reduced approximately to 2/3.

Finally some combinations of solar control glasses with ordinary solar shading systems were simulated. The best performances were achieved for I50 and I54 which result from the combination of a solar control glass (body tinted and hard coating respectively) with external venetian lamellas made of aluminium. In these cases, total energy demands of 11kWh/m^2.year and 14kWh/m^2.year were correspondingly obtained without the use of mechanical cooling. To remove completely the hours of overheating above 22ºC, air-conditioning system may be used and as a result the total energy demands increase to 15kWh/m^2.year and 17kWh/m^2.year respectively (this is half of the energy consumption achieved with the reference glazing).

6.4.2 Lisbon

6.4.2.1 The reference system

Regarding the heating demand, the situation for Lisbon is similar to Copenhagen. The envelopment solutions are very good concerning the Portuguese climate (low U-values: 0.4W/m^2.K for exterior wall, roof and ground; and 0.68W/m^2K for the window) and the heat exchanger has a high efficiency (0.85).

The difference comes with the level of indoor comfort. With the reference glazing and without mechanical cooling the number of hours of temperature above 26ºC is extremely high, 1009 hours and the PPD index is 28% which is much higher than the standard maximum, 10%.
When trying to remove the hours of overheating with mechanical cooling, the panorama is different from Copenhagen. As there are much more hours of overheating the cooling demand to remove them is very high, 61kWh/m^2.year. This value is approximately doubled of 32kWh/m^2.year which is

the standard maximum cooling demand calculated in accordance with the Portuguese building code [16].

This means that even being the sum of the energy for heating, cooling and lightning (65kWh/m^2.year) much lower than the correspondent standard required value (104kWh/m^2.year), the office building with this reference glazing does not fulfil the standard requirements.

In this way, it is very important to find solutions of solar shading systems that can reduce the cooling demand to a lower value than the requirement.

6.4.2.2 The different solar shading systems

For the building in Lisbon without mechanical cooling, only four solutions of solar shading systems (the external roller blinds C16 and C17 and the combinations of solar control glass with external roller blinds I48 and I52) accomplish the standard indoor environment requirements and are quite close to the admissible limit. This means that, in opposition to Copenhagen, an office building in Lisbon always require an air-conditioning system.

Even with an air-conditioning system, not all the solutions for the solar shading systems can fulfil the energy requirements for the cooling demand. As referred before, according to the Portuguese building code, the cooling demand for an office building in Lisbon as the one studied can not be higher than 32kWh/m^2.year. This means that some of the simulated solar shading systems can not be used in such a building in Lisbon. For instance, the internal roller blinds and the internal and interpane venetian blinds can never be used.

As in Lisbon there is a higher problem of overheating than in Copenhagen, the use of the shading systems is needed during longer periods of time. In this way, as the shading systems reduce the daylight into the rooms, it would be expected that the yearly energy needed for electrical lightning would be higher in Lisbon. Indeed, this is only true for roller blinds. For systems composed of slats (like the venetian blinds and glass lamellas) as the solar altitude is higher in Lisbon than in Copenhagen, the cut-off angle is lower in Lisbon. This means that in Lisbon higher levels of daylight can reach the room through the space between the slats. Also the general luminance level of the sky is higher in Lisbon than in Copenhagen. As a consequence, the yearly electrical lightning demand may be lower in Lisbon than in Copenhagen, even with a higher need for use of shading systems in Lisbon.

7. Daylight performance evaluation

In chapter **6.Energy and indoor comfort evaluation**, using *BuildingCalc/LightCalc*, calculations were performed of the yearly electrical lightning demand to keep a general level of illuminance of 200lux and a level of 500lux in working areas.

In this chapter, the goal will be to check how the daylight performance of different solar shading systems is for a specific situation (certain time, certain sky conditions and certain position of the solar shading system). Using *LightCalc* instead of the combination *BuildingCalc/LightCalc*, the daylight factor will be evaluated at the working plane.

7.1 Criteria and requirements

There are different parameters that may be used to evaluate the daylight performance of a building: the daylight factor, the working plane illuminance, the illuminance uniformity on the working plane, the absolute luminance in the field of view and the luminance ratios between the working plane, walls and screens. [7]

In this chapter the daylight performance of different solar shading systems combined with the reference glazing was assessed by the daylight factor at the working plane.
In an office building the general level of daylight factor should be around 2% while for working areas it should be 5%. These values correspond respectively to 200lux and 500lux during an overcast situation (in which the global illuminance is commonly 10000lux).

The daylight factor was calculated in one specific point of the room, point A(x=10m; y=8m; z=0.85m) (see **Figure 7.1**). This point is centred according to the façade and it is 0.85m offset from the floor (working plane) and 2m offset from the back wall. It was assumed that no working areas will be set after this point (when looking from the window).

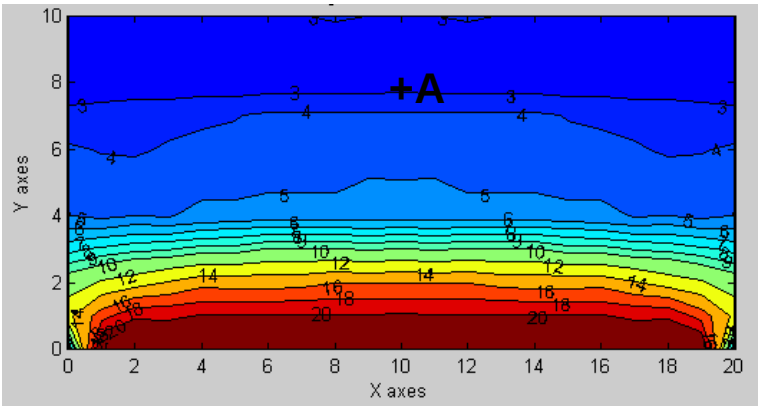

Figure 7.1 - LightCalc picture of the room showing point A(x=10m; y=8m; z=0.85m) where the daylight factor was determined for each solution of solar shading system combined with the reference glazing. Different colours represent different levels of daylight factor.

The daylight factor for the different solar shading systems was calculated for the active position: in order to avoid the use of electrical lightning during an overcast sky, the daylight factor should be around 5% in point A. This could seem a contrasense at first glance since the typical situation is that the shading systems are removed during overcast skies. The idea was to simulate the days in which the sky is constantly changing from sunny to overcast and vice-versa. In real situations it is not good to be constantly changing the position of the solar shading systems according to the sky conditions. Even if the control is automatic, the frequent movements of the shading systems may interfere with the concentration and efficiency levels of workers.

7.1.1 Roller blinds

For roller blinds the active position means that they are completely rolled down: this is the way of blocking the direct sun during sunny days in order to reduce the solar gains through the window.

7.1.2 Slat systems (venetian blinds and glass lamellas)

For the slat systems (venetian blinds and glass lamellas) the daylight performance was evaluated for the cut-off position (which corresponds to open the slats as far as possible without letting the sunshine directly through the system - see **Figure 7.2**). The cut-off position depends on the actual position of the sun and for this reason the most critical situation for daylight is during winter time when the sun is lower. In this case the cut-off angle of the slats is higher, which means that less daylight enters the room. Due to different latitudes, under the same circumstances (same time and same slat shading system) the cut-off angle is higher for Copenhagen than for Lisbon.

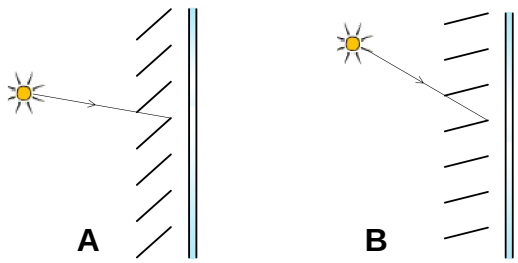

Figure 7.2 - Cut-off position for a solar shading system composed of slats. Figures (a) and (b) refer to different positions of the sun.

According to the sun path that can be printed using *BuildingCalc/LightCalc*, the lowest sun position occurs on December 21st (day 355). It is around 12.00 o'clock that the sun is normal to the façade (solar azimuth angle, γ, $\cong$ 0º). At this time, the solar altitude angle, β, is around 11.2º in Copenhagen and 27.3º in Lisbon. The cut-off position for the solar shading systems composed of slats will be calculated for this time.

To calculate the cut-off angle, α_c, first the profile angle, θ, must be determined. The profile angle is the projection of the solar altitude angle on a vertical plane perpendicular to the façade. However, as 12.00 o'clock was chosen, the solar azimuth angle is approximately 0º and the profile angle was assumed to be equal to the solar altitude angle (see **Figure 7.3**).

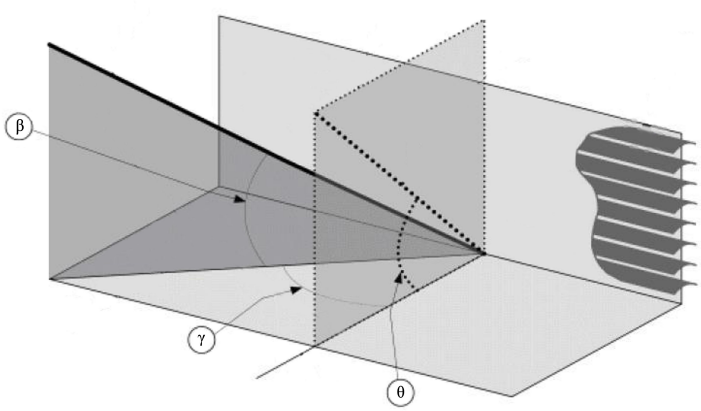

Figure 7.3 - Drawing of a building façade with the representation of the solar altitude angle, β, solar azimuth angle, γ, and profile angle, θ.

The cut-off angle, α_c, may be calculated by the following equation valid for α_c>0:
(For a better understanding see **Figure 7.4**)

$$\frac{w}{2} \times sin\,\alpha_c + \frac{w}{2} \times cos\,\alpha_c \times tan\,\theta = \frac{p}{2} \qquad (7.1)$$

where α_c is the cut-off angle in degrees, θ is the profile angle in degrees, w is the width of the slats in mm and p is the distance between slats in mm.

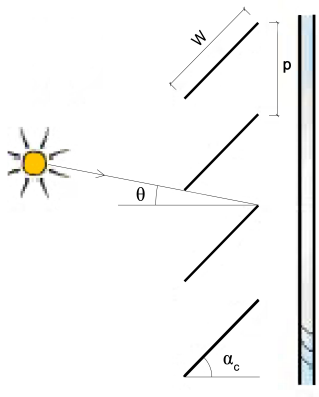

Figure 7.4 - Drawing of a slat system showing the profile angle, θ, the cut-off angle, α_c, the slats width, w and the distance between slats, p.

In **Table 7.1** the cut-off angle is presented for each slat system and for both Copenhagen and Lisbon.

Table 7.1- Cut-off angle, α_s, for the different slat systems on December 21st at 12.00 o'clock (the profile angle is 11.2º for Copenhagen and 27.3º for Lisbon)

type of solar shading system	w [mm]	p [mm]	Copenhagen α_s [º]	Lisbon α_s [º]
D. Internal venetian blinds				
Valid for all	25	20	41	18
D. Interpane venetian blinds				
Valid for all	22	16	36	14
F. External venetian blinds				
29. Aluminium lamellas_60mm	60	52	47	23
30. Aluminium lamellas_80mm	80	72	51	26
31. Aluminium lamellas_100mm	100	92	53	28
G. Glass lamellas				
Valid for all	500	500	68	35

The relation between the slat width and the distance between two consecutive slats has an important influence on the cut-off angle. This is the reason for such different cut-off angles when comparing different slats systems.

7.1.3 Reference glazing and solar control glazings

For the reference glazing and solar control glazings studied there is no active or non active position. These systems are not flexible to different sky conditions. Thus the daylight factor at point A should be 5% in order to avoid the use of electrical lightning during the most critical situation for daylight, the overcast days.

7.2 Results

In **Table 7.2** the daylight factor [%] calculated with *LightCalc* is presented for the reference glazing and for the different solar shading solutions. The values refer to point A.
As stated before the roller blinds are completely activated while the slats systems (venetian blinds and glass lamellas) are in the cut-off position.
For the slats systems there are two different values that correspond to distinct cut-off positions for Copenhagen and Lisbon.

Table 7.2 - Daylight factors calculated in point A(x=10m; y=8m; z=0.85m) with different solar shading systems applied on the façade of the office building

ID	**Position/Type** (Product name)	**Daylight factor in point A(x=10m; y=8m; z=0.85)**	
		Copenhagen	**Lisbon**
REF	**Reference Glazing**	2.5%	
A	**Internal Roller Blinds**		
1	Verosol Roller 818-000 UT light-grey	1.2%	
4	Verosol Roller 875-000 BO light-grey	0.1%	
10	Verosol SilverScreen white ED01 HT	0.2%	
B	**Interpane Roller Blinds**		
12	Verosol Roller 818-000 UT light-grey	1.2%	
13	Verosol Roller 875-000 BO light-grey	0.1%	
14	Verosol SilverScreen white ED01 HT	0.2%	
C	**External Roller Blinds**		
16	Verosol SilverScreen white ED01 HT	0.2%	
D	**Internal Venetian Blinds** (cut-off angle: CPH - 41º;LIS- 18º)		
18	Luxaflex venetian blind 8% Perforation 2053	0.4%	1.0%
19	Luxaflex venetian blind 8% Perforation 6127	0.2%	0.7%
20	Luxaflex venetian blind 8027	0.5%	1.1%
21	Luxaflex venetian blind High Mirror 4078	0.4%	1.1%
E	**Interpane Venetian Blinds** (cut-off angle: CPH - 41º;LIS- 18º)		
24	Luxaflex venetian blind 8% Perfor 2053	0.3%	1.0%
25	Luxaflex venetian blind 8% Perfor 6127	0.3%	0.8%
27	Luxaflex venetian blind High Mirror 4078	0.4%	1.1%
28	Luxaflex venetian blind Thermostop 2383	0.4%	1.1%
F	**External Venetian Blinds**		
29	Aluminium lamellas_60mm (cut-off angle: CPH - 47º; LIS- 23º)	0.1%	0.5%
30	Aluminium lamellas_80mm (cut-off angle: CPH - 51º; LIS - 26º)	0.2%	0.7%
31	Aluminium lamellas_100mm (cut-off angle: CPH - 53º; LIS - 28º)	0.2%	0.7%
G	**External Glass Lamellas** (cut-off angle: CPH - 68º; LIS - 35º)		
32	SGG_Antelio Silver_500mm	1.7%	1.8%
33	SGG_Antelio Clear_500mm	1.1%	1.3%
34	SGG_Reflectasol Grey_500mm	0.5%	0.9%
35	Glav_Stopsol Silverlight Green_500mm	0.6%	0.7%
H	**Solar Control Glazings**		
36	Pilkington Artic Blue™	1.9%	
40	Pilkington Suncool HP Silver 50-30™	1.6%	
41	SSG Antelio Silver	2.0%	
43	SSG Antelio Esmeralda	1.6%	
45	SSG Reflectasol Green	0.8%	
46	SSG Cool-Lite KS147	1.5%	

7.3 Discussion of the results

The results show that using the reference glazing the daylight factor in point A is 2.5%. This value corresponds to an illuminance of 250 lux during an overcast sky which is enough for general light level in office buildings but not when performing tasks (500lux is the requirement). This indicates that electrical light must be switched on when performing tasks during overcast skies.

For the solar control glazings the daylight factors in point A vary between 0.8% and 2.0%. In this case, electrical lightning may be needed during overcast days not only when performing tasks but also to keep the required general light level in the office.

This situation could be improved using solar control glasses whose optical properties vary according to the sky conditions: these glasses become darker under sunny skies avoiding the solar gains to enter the room, also the light transmittance decreases in this case; on the other hand

under overcast skies the glass becomes clear again and the light transmittance increases. These types of glass could decrease the electrical lightning demand during overcast days. However the design tools used in this dissertation (*WIS* and *BuildingCalc/LightCalc*) are not able to evaluate their performance.

For the roller blinds the daylight factor in point A is very low (for instance 0.1% and 0.2% for black-out and half-transparent blinds respectively). This means that if they are activated for a sunny day and if it turns into overcast and they are not retracted, high electrical lightning demand may be needed to fulfil the requirements for indoor lightning level. In this way, the roller blind does not seem the best solution when thinking about avoiding the adjustments of shading systems that may disturb the workers concentration and efficiency.

For the venetian blinds different daylight performances for Copenhagen and Lisbon can be achieved because of the different cut-off positions comparing both cities. Because of different latitudes the solar altitude in Copenhagen is lower than in Lisbon. In this way comparing Copenhagen with Lisbon for the same venetian blind, for Copenhagen the cut-off position angle is higher which means that less daylight enters the room. This is the reason for the lower values obtained for the daylight factor in the office building in Copenhagen when compared to the office in Lisbon.
The values achieved for the daylight factor (between 0.1% and 0.5% for Copenhagen and 0.5% and 1.1% for Lisbon) are better than the ones obtained with the roller blinds especially for Lisbon. This is due to the possibility that the daylight has to enter the room through the space between the slats. However, the daylight factors obtained show that also the venetian blinds should be retracted when the sky turns from sunny to overcast in order to decrease the energy consumption for electrical lightning.

Excluding the reference glazing and the solar control glasses, the glass lamellas are the ones that have the best performance during overcast sky even if they are activated for the cut-off angle for a previous sunny sky. This is due to the high visual transmittance of the glass. This system seems to be a promising solar shading system when trying to reduce the number of adjustments in solar shading systems due to sky conditions changes.

The results also show that the position (external, interpane and internal) of the shading systems do not interfere with the indoor daylight performance. External, interpane and internal roller blinds have equal performance when evaluated under an overcast sky. The same is valid for the venetian blinds if activated for the same cut-off angle.

8. Some tips on how to overcome the lack of data available for solar shading systems

As it was stated before there is a lack of information about the properties of the solar shading systems available on the market. Most manufactures do not have available the thermal properties of their products and regarding optical properties they only have integrated data and no spectral data. In this way, it is more difficult for the designer to access the performance of the solar shading systems.

In this chapter, some tips on how to make use of the data usually given by the manufactures will be suggested (for *WIS* and *BuildingCalc/LightCalc* simulations). Also some examples will be illustrated and the results compared with the ones obtained with the use of complete data.

8.1 General Assumptions

Often the shadings properties that are required in *WIS* to characterize a shading system are not given by the manufactures.
For instance, some of the *WIS* inputs are the thermal conductivity, outdoor and indoor IR emissivities and IR transmissivity of the material that composes the shading system and usually manufactures do not have available this information. Regarding optical data manufactures only give simplified information as the solar transmittance (τ_S), solar reflectance (ρ_S), light transmittance (τ_V) and light reflectance (ρ_V). These values represent integrated data and include direct and diffuse components (which should be set separately in *WIS*).

In **Table 8.1** some tips are suggested of how to input new solar shadings systems in *WIS* when the complete technical information is not available (the tips are organized according to the different *WIS* input fields: geometry, thermal properties and optical properties).

Table 8.1 - Tips on how to use simplified data from manufactures

***WIS* input field**	**Properties**	**Tips**
Geometry	- *Roller blinds* (thickness) - *Slat shading device* (thickness, slat chord width, crown height, slat pitch)	The shading system geometry must be given by the manufacture
Thermal properties	Material conductivity	- *Roller blinds* (assume 0.2W/mK for ordinary fabrics) - *Venetian blinds* (assume 150W/mK for aluminium slats)

Table 8.1 (Cont.1) - Tips on how to use simplified data from manufactures

Thermal properties (Cont.)	Material IR emissivity (outdoor/indoor)	Assume 0.5 for metallic surfaces and 0.8 for non-metallic surfaces*.
	Material IR transmissivity	Assume that it is zero.
Optical properties	- *Roller blinds* Integrated data (solar, visual and UV) for outdoor and indoor transmittance and reflectance for different angles of incidence - the values must be separated into direct and diffuse components	- *Roller Blinds* Assume that the optical properties are equal for the different angles of incidence. However, assume that for 90º or -90º angles of incidence there is only reflectance and no transmittance Assume that all of the transmittance is direct and that all of the reflectance in diffuse. (Assuming that the transmittance is direct is valid for the normal angle of incidence. For different angles of incidence the shape of holes has an influence on the direct and diffuse components of the transmittance through the fabrics. Through thick and long holes (tunnel shape) the diffuse component is higher while through wide and short holes the direct component is higher. More studies should be done regarding this subject) Assume that the optical properties are equal for the outside and inside surfaces If no information about the UV transmittance (τ_{UV}) and UV reflectance (ρ_{UV}) is given by the manufacture assume that they are equal to the solar transmittance (τ_S) and solar reflectance (ρ_S)*
	- *Venetian blinds* Integrated data (solar, visual and UV) for transmittance and for outdoor and indoor reflectance for normal angle of incidence - the values must be separated into direct and diffuse components	- *Venetian Blinds* Assume that all of the transmittance is direct and that all of the reflectance in diffuse. (see comments above for the same assumption for the roller blinds) Assume that the optical properties are equal for the outside and inside surfaces If no information about the UV transmittance (τ_{UV}) and UV reflectance (ρ_{UV}) is given by the manufacture assume that they are equal to the solar transmittance (τ_S) and solar reflectance (ρ_S)*

* These suggestions are in accordance with typical solar shading systems available in the *WIS* database.

8.2 Case studies

In this chapter, simulations for some solar shading systems studied before were performed but using the data usually given by the manufactures and doing the assumptions above proposed. (For the simulations, the solar shading systems were integrated in the landscaped office building in Copenhagen)

The purpose is to compare the results between the use of complete and simplified data and analyse the influence of the proposed simplifications and assumptions on the final performance of the office room. The goal is also to demonstrate whether or not results closer to reality can be obtained when using simplified data.

8.2.1 Roller blinds

Two different fabrics for roller blinds with different openness factors (OF) were chosen:

1. Verosol Roller 818-000 (40%OF) - **A1**
2. Verosol SilverScreen black EB01 (4%OF) - **A11 and C17**

The first one was assessed as internal roller blind and the second as internal and external.

8.2.1.1 Data available from manufacture

In **Table 8.2** the data available from *Verosol* manufacture website [35] for both roller blind fabrics is presented.

Table 8.2 - Data available from the manufacture

Verosol 818-000 (40% OF)	**Verosol SilverScreen black EB01 (4%OF)**
thickness = 0.18mm τ_S=0.44 ρ_S=0.34 τ_V=0.44 ρ_V=0.33 τ_{UV}=0.43 front surface - metallic back surface - non-metallic	thickness = 0.5mm τ_S=0.05 ρ_S=0.75 τ_V=0.05 ρ_V=0.74 τ_{UV}=0.05 front surface - metallic back surface - non-metallic

8.2.1.2 How to use the data available from the manufacture

In **Table 8.3**, the data used in *WIS* based on available data from the manufacture (**Table 8.2**) and assumptions previously suggested (**Table 8.1**) are presented. (For these products the complete data is available in WIS database and some properties are presented in **Table 6.2** and **Table 8.6**)

Table 8.3 - Data used in *WIS* based on available data from the manufacture and assumptions previously suggested.

Verosol 818-000 (40% OF)	Verosol SilverScreen black EB01 (4%OF)
Geometry Thickness =0.18mm **Thermal properties** Material conductivity = 0.2W/mK* IR emissivity outdoor = 0.5* IR emissivity indoor = 0.8* IR transmissivity = 0* **Optical properties** τ_S=0.44 ρ_S=0.34 τ_V=0.44 ρ_V=0.33 τ_{UV}=0.43 ρ_{UV}=0.34* Only direct transmission* Only diffuse reflection* No incidence angle dependence except for the 90º and -90º for which there is only reflection and no transmission*	**Geometry** Thickness =0.5mm **Thermal properties** Material conductivity = 0.2W/mK* IR emissivity outdoor = 0.5* IR emissivity indoor = 0.8* IR transmissivity = 0* **Optical properties** τ_S=0.05 ρ_S=0.75 τ_V=0.05 ρ_V=0.74 τ_{UV}=0.05 ρ_{UV}=0.75* Only direct transmission* Only diffuse reflection* No incidence angle dependence except for the 90º and -90º for which there is only reflection and no transmission*

* Assumptions

8.2.2 Venetian Blinds

Regarding venetian blinds, two different examples were chosen:

1. Luxaflex Venetian Blind High Mirror 4078 - **D21**
2. Warema aluminium lamellas 60mm (Raffstoren 94 A6 RAL 9006) - **F29**

While the first one refers to an internal venetian blind from *Luxaflex* manufacture which has the complete data available in *WIS*, the second refers to an external venetian blind made of aluminium lamellas and their complete properties are not available on *WIS*. In this way, for this last case the results obtained using simplified data can not be compared to the ones with complete data.

8.2.2.1 Data available from manufacture

In **Table 8.4** the data available for both cases is presented.

Table 8.4 - Data available from the manufacture

Luxaflex Venetian Blind High Mirror 4078	**Warema aluminium lamellas 60mm (Raffstoren 94 A6 RAL 9006)**
thickness = 0.22mm slat chord width = 25mm crown height = 2mm slat pitch =20mm τ_S=0 ρ_S=0.83 τ_V=0 ρ_V=0.83 both surfaces painted	thickness = 0.5mm slat chord width = 60mm crown height = 5mm slat pitch = 52mm τ_S=0 ρ_S=0.4* τ_V=0 ρ_V=0.4* front surface - metallic back surface - non-metallic

* As the lamellas are placed outside, their surface is exposed to the exterior environmental conditions and easily their reflectance can be long term reduced. This situation must be taken into account and the original reflectance given by the manufacture must be decreased (the original value was 0.51)

8.2.2.2 How to use the data available from the manufacture

The data used in *WIS* based on available data from the manufacture and assumptions previously suggested are presented in **Table 8.5**.

Table 8.5 - Data used in *WIS* based on available data from the manufacture and assumptions previously suggested

Luxaflex Venetian Blind High Mirror 4078	**Warema aluminium lamellas 60mm (Raffstoren 94 A6 RAL 9006)**
Geometry thickness = 0.22mm slat chord width = 25mm crown height = 2mm slat pitch =20mm **Thermal properties** Material conductivity = 150 W/mK* IR emissivity outdoor = 0.8 (painted surface)* IR emissivity indoor = 0.8 (painted surface)* IR transmissivity = 0* **Optical properties** τ_S=0 ρ_S=0.83 τ_V=0 ρ_V=0.83 τ_{UV}=0* ρ_{UV}=0.83* (Optical properties equal for both sides*)	**Geometry** thickness = 0.5mm slat chord width = 60mm crown height = 5mm slat pitch = 52mm **Thermal properties** Material conductivity = 150 W/mK* IR emissivity outdoor = 0.8 (painted surface)* IR emissivity indoor = 0.8 (painted surface)* IR transmissivity = 0* **Optical properties** τ_S=0 ρ_S=0.4 τ_V=0 ρ_V=0.4 τ_{UV}=0* ρ_{UV}=0.4* (Optical properties equal for both sides*)

* Assumptions

8.2.3 Results and Discussion

For a better understanding of the different results when using simplified and complete data, the complete data (from *WIS*) and simplified data (from manufacture and assumptions) for the analysed solar shading systems are presented in **Table 8.6**.The spectral optical properties are not presented but can be consulted in the *WIS* database.

In **Table 8.7**, the results of the performance of the landscaped office room in Copenhagen obtained when using complete and simplified data are presented. When simplified data was used the name of the solar shading system is preceded by the word “SIMPLIFIED”.

The results show that the simplifications made have a very slight influence on the performance of the solar shading systems: the analysed parameters do not have significant variations. For instance, the yearly total energy consumption of the landscaped office room has a maximum variation of 8% when comparing the use of complete data with the use of simplified data.

However the small differences on the results can have different reasons.
For example, the differences on the heating demand depend directly on the thermal properties defined for the shading. For instance, for the internal roller blind *Verosol Roller 818-000* an IR-transmissivity of 0 was defined for the simplified model while the real product has an IR-transmissivity of 0.158. In this way, it is expected that the U-value of the glazing combined with the internal blind for the simplified model is lower than the real one. Consequently the heating demand for the office room will be lower when using the simplified data.

Regarding the need for electrical lightning, the results show that the electrical lightning demand is lower when simplified data is used which means that more natural light is entering the room with the simplified model. The reason for this can be the way how the transmittance was defined (when different than zero): it was assumed that all of the transmittance is direct and there is no diffuse component (in reality there is also a diffuse component).

The different numbers of hours of overheating obtained (when mechanical cooling is not used) for the use of complete data and simplified data can be partly explained by the difference on the electrical lightning demand. If the electrical lightning demand is lower, lower are the internal loads and less are the hours of overheating.
However the g-value of the glazing combined with the shading also has an influence: higher the g-value is, lower should be the number of hours of overheating. The use of integrated data instead of spectral data can be the reason for different g-values.

For the internal venetian blind simulated there was a decrease of 40 hours above 26ºC when using simplified data. It would be expected the opposite as the g-value is higher for the simplified case. No reason was found for this.

The results obtained for the last case study, *Warema aluminium lamellas 60mm (Raffstoren 94 A6 RAL 9006)*, can not be compared since there is no available data characterizing this system in *WIS*.

Apparently the results show that simplified data can be used when evaluating the energy performance of solar shading systems: the results obtained for the energy performance of the building using simplified data are quite close to the ones when using complete data.
However only few cases were studied, more detailed studies should be done in this field and for different types of solar shading systems to assure that simplified data can be used in any case in the early design phase to assess the performance of solar shading systems.

The main problem of not using spectral data could be when evaluating the performance of solar shading systems regarding the influence that they have in the colour of the light that enters the room. Using integrated data, solar shading systems with different colours can not be distinguished, the indoor light colour will be the same.

Table 8.6 - Comparison of the complete and simplified data of the solar shading systems

ID	Position/Type (Product name)	Description	t [mm]	thermal properties				optical properties			
				λ [W/mK]	IR ε_{out} [-]	IR ε_{ind} [-]	IR transm*	τ_S [-]	ρ_S [-]	τ_V [-]	ρ_V [-]
A	**Internal Roller Blinds**	**(50mm air gap between the glazing and the shading)**									
1	Verosol Roller 818-000 UT light-grey	ultra transparent (OF=40%), f. metallic, b. light-grey	0.18	0.20	0.510	0.811	0.158	0.44	0.34	0.44	0.33
1S	SIMPLIFIED_Verosol Roller 818-000 UT light-grey	ultra transparent (OF=40%), f. metallic, b. light-grey	0.18	0.20	0.500	0.800	0.000	0.44	0.34	0.44	0.33
11	Verosol SilverScreen black EB01 HT	half transparent (OF=4%), f. metallic, b. black	0.50	0.15	0.160	0.810	0.000	0.05	0.75	0.05	0.74
11S	SIMPLIFIED_Verosol SilverScreen black EB01 HT	half transparent (OF=4%), f. metallic, b. black	0.50	0.20	0.500	0.800	0.000	0.05	0.75	0.05	0.74
C	**External Roller Blinds**	**(50mm air gap between the glazing and the shading with free ventilation)**									
17	Verosol SilverScreen black EB01 HT	half transparent (OF=4%), f. metallic, b. black	0.50	0.15	0.160	0.810	0.000	0.05	0.75	0.05	0.74
17S	SIMPLIFIED_Verosol SilverScreen black EB01 HT	half transparent (OF=4%), f. metallic, b. black	0.50	0.20	0.500	0.800	0.000	0.05	0.75	0.05	0.74
D	**Internal Venetian Blinds**	**(50mm air gap between the glazing and the shading)**									
21	Luxaflex venetian blind High Mirror 4078	w=25mm, c=0mm, p=20mm, f. high mirror, b. grey stone	0.22	100.00	0.710	0.680	0.000	0.00	0.83	0.00	0.83
21S	SIMPLIFIED_Luxaflex venetian blind High Mirror 4078	w=25mm, c=0mm, p=20mm, f. high mirror, b. grey stone	0.22	150.00	0.800	0.800	0.000	0.00	0.83	0.00	0.83
F	**External Venetian Blinds**	**(50mm air gap between the glazing and the shading with free ventilation) - integrated data based on Warema manufacture**									
29	SIMPLIFIED_Warema_Aluminium lamellas_60mm	w=60mm; c=5mm; p=42mm	0.50	150.00	0.800	0.800	0.000	0.00	0.40	0.00	0.40

*IR transm= IR transmissivity

Table 8.7 - Comparison of results obtained with complete and simplified data. Landscaped office building in Copenhagen

ID	Position/Type (Product name)	system properties[1]						without mechanical cooling					with mechanical cooling[2]				
		U-value [W/m²K]	g-value [-]	SSC [-]	τ_V [-]	VSC [-]	Ra [%]	heating [kWh/m²]	lightning [kWh/m²]	total[3] [kWh/m²]	T>26°C [h]	PPD [%]	heating [kWh/m²]	cooling [kWh/m²]	lightning [kWh/m²]	total[4] [kWh/m²]	PPD [%]
REF	**Reference Glazing**	0.68	0.49	1.00	0.68	1.00	96	0.55	3.21	8.56	260	12	0.61	22.58	3.21	31.20	7
A	**Internal Roller Blinds**																
1	Verosol Roller 818-000 UT light-grey	0.60	0.40	0.82	0.33	0.49	95	0.50	3.78	9.94	182	11	0.54	17.83	3.62	27.42	7
1S	SIMPLIFIED_Verosol Roller 818-000 UT light-grey	0.57	0.36	0.73	0.33	0.49	95	0.45	3.65	9.57	156	10	0.47	16.19	3.53	25.47	7
11	Verosol SilverScreen black EB01 HT	0.51	0.25	0.51	0.04	0.06	94	0.41	7.28	18.61	101	9	0.41	12.38	6.82	29.83	8
11S	SIMPLIFIED_Verosol SilverScreen black EB01 HT	0.57	0.27	0.55	0.04	0.06	95	0.49	6.81	17.51	112	9	0.49	13.24	6.38	29.66	8
C	**External Roller Blinds**																
17	Verosol SilverScreen black EB01 HT	0.62	0.03	0.06	0.03	0.04	95	0.78	6.31	16.56	0	8	0.78	2.97	6.17	19.18	8
17S	SIMPLIFIED_Verosol SilverScreen black EB01 HT	0.62	0.03	0.06	0.04	0.06	95	0.78	6.00	15.78	0	8	0.78	2.97	5.86	18.40	8
D	**Internal Venetian Blinds**																
21	Luxaflex venetian blind High Mirror 4078	0.58	0.23	0.47	0.00	0.00	90	0.46	4.51	11.72	214	12	0.49	19.79	4.30	31.02	7
21S	SIMPLIFIED_Luxaflex venetian blind High Mirror 4078	0.59	0.25	0.51	0.00	0.00	90	0.47	4.45	11.58	173	11	0.50	17.60	4.25	28.72	7
F	**External Venetian Blinds**																
29	SIMPLIFIED_Warema_Aluminium lamellas_60mm	0.62	0.01	0.02	0.00	0.00	0	0.67	4.14	11.00	0	8	0.67	4.00	4.09	14.88	8

[1] For the venetian blind the properties refer to the system completely activated (90º slat position)
[2] The setpoint for cooling is 22ºC, so when the mechanical cooling is activated there are no hours above 22ºC
[3] Total energy demand = heating demand + 2.5 lightning demand
[4] Total energy demand = heating demand + cooling demand + 2.5 lightning demand

9. Conclusions and further work

The combination of *WIS* and *BuildingCalc/LightCalc* is a very promising tool when evaluating and comparing the performance of buildings with different types of solar shading systems in an early design phase. From the simple model of the room and the thermal/optical properties of the shadings systems it is possible to calculate in an hourly basis the yearly energy demand for heating, cooling and lightning as well as some indoor comfort parameters.

The method on how to evaluate the performance of different solar shading systems using *WIS* and *BuildingCalc/LightCalc* was illustrated for a case study: a landscaped office building located in Copenhagen and then in Lisbon. Different types of solar shading systems were evaluated for the façade of the office. Apart from small tricks presented through the dissertation the method is quite user friendly.

When selecting a solar shading system two main characteristics must be taken into account: the solar shading performance (assessed by g-value - solar heat gain coefficient) and the daylight performance (assessed by the τ_V - visual transmittance). Usually good shading devices according to solar shading performance are poor in daylight performance. It is very important that a solar shading system is flexible to different sky conditions. In this way it can be activated during warm and sunny days to avoid the risk of overheating and retracted when solar heat gains and light are needed in the rooms.

For the case study it was clear the difference between the North Europe (Copenhagen) and South Europe (Lisbon) climates regarding the solar shading systems. For instance, using the same solar system for Lisbon and for Copenhagen the cooling demand in Lisbon is in some cases doubled than in Copenhagen. For some cases this cooling demand for the office room in Lisbon is higher than the standard requirement which means that some solutions of shading systems should not be used in Portugal.

One of the main advantages of *BuildingCalc/LightCalc* is the ability of performing dynamic simulations. Different setting for distinct periods of the day (working hours and non working hours) and year (summer and winter) can be defined making simulations closer to reality.

Another benefit is that *BuildingCalc/LightCalc* works with *WIS* which is a promising database for windows components (panes, shading devices, ect). *BuildingCalc/LightCalc* is able to import the text files generated by *WIS* with the thermal/optical properties of glazings and shading systems combinations. In this way, every shading device existing in *WIS* can be simulated in a room using *BuildingCalc/LightCalc*.

Another important profit from *BuildingCalc/LightCalc* is that it is able to calculate the yearly electrical lightning demand taking into account the hours in which the shading system is activated and in which less daylight enters the room. At the same time this electrical lightning demand contributes to the internal loads of the room.

On the other hand the way the shading system is activated is not yet very close to reality. The shading system is activated when the indoor temperature is higher than the cooling setpoint. This means that a shading system can be activated during overcast situations in which the indoor temperature is higher than the cooling setpoint. In this way the natural light entering the room is less and the electrical lightning demand may be wrongly increased. In this way the shading activation should also somehow depend on the luminance of the sky. It would be also interesting to control the shading systems with respect to indoor daylight and glare.

Nowadays there is still a lack of data about the angular and spectral properties of the solar shading systems. Manufactures rarely have this information available: often thermal properties are not available and optical properties are given as integrated values instead of spectral values. Some suggestions were given on how to make use of the available data from manufactures. It seems that the use of simplified data for solar shading systems does not have a large influence on the final performance of buildings. However, only few cases were studied. More research should be done on this area and for different types of solar shading systems.

PART B. GLASS LAMELLA SYSTEMS: COMPARING MEASUREMENTS WITH *IESVE/RADIANCE* SIMULATIONS

10. Introduction and goal

As referred in the **Part A** of this dissertation, the glass lamellas are a promising type of solar shading system: besides acting as typical solar shading systems reducing the solar gains and consequently the cooling demand, they may at the same time allow good indoor daylight levels thanks to the transparent properties of glass. On the other hand during overcast days if they are correctly tilted they may slightly increase the indoor daylight especially on the back part of the room.

Some daylight measurements were performed in the Daylight Laboratory at SBi (Danish Building Research Institute, in Hørsholm, in Denmark) regarding the research project *Development of new solar shading systems based on daylight-directing solar control glass* lamellas lead by Steen Traberg-Borup.

The daylight measurements in the Daylight Laboratory at SBi were performed in two experimental rooms (reproducing office rooms): one with an ordinary glass façade (reference room) and another one equal but equipped with a system of glass lamellas on its façade (test room).
Illuminance levels in specific points of both rooms (working plane and ceiling) were measured under different sky conditions and for different positions of the glass lamellas. The results obtained for both rooms were compared and the performance of the glass lamellas evaluated.

The goal of Part B of this dissertation is to build the model of the rooms using *IESve/Radiance* [39] and assess how close to the measurements can the results from the simulations be. *IESve/Radiance* is a simplified and user-friendly version of the original *Radiance*. The purpose is to test how accurate is *IESve/Radiance* assessing the daylight performance of rooms where glass lamellas are applied.

11. The Daylight Laboratory at SBi

11.1 Description of the experimental rooms

11.1.1 Geometry

The Daylight Laboratory in Hørsholm (Denmark) consists of two identical experimental rooms raised 7m above the ground to minimise shading from surrounding buildings and trees. (see **Figure 11.1**). The latitude and longitude of Daylight Laboratory are 55.86º north and 12.49º east respectively and the rooms are oriented 7.5º east of the exact south direction.

Figure 11.1 - Picture of the Daylight Laboratory at SBi

The two experimental rooms are identical, each measuring 3.5m (width) by 6.0m (depth) with a floor to ceiling height of 3.0m. (see **Figure 11.2**)

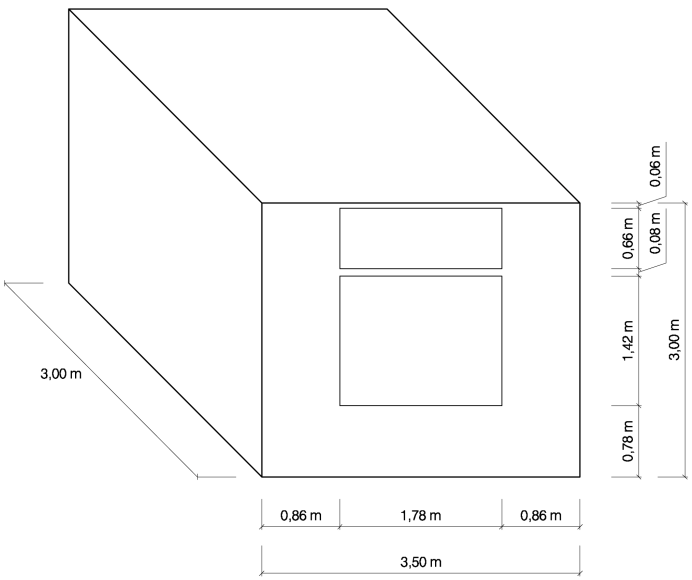

Figure 11.2 - Geometry of the experimental rooms of the Daylight Laboratory at SBi

11.1.2 Landscape

The space in front of the experimental rooms is a field of grass and it is essentially empty from obstructions, apart from the distant row of trees towards south and the group of trees towards the south-west direction (see **Figure 11.3**)

Figure 11.3 - Landscape view from the Reference room of the Daylight Laboratory at SBi

11.1.3 The windows

Each room has two windows: one larger in the middle of the façade and another one smaller upper in the façade. The larger window is 1.78m wide by 1.42m high and it is 0.78m from the floor. The smaller one is 1.78m wide by 0.66m high and it is 0.08m offset from the larger window. Both windows are centred with respect to the lateral walls. (see **Figure 11.2**)

The windows of the experimental rooms are double-pane assembly with a low-emissivity coating and argon filling from Pilkington (Optitherm S). The U-value in the middle of the glazing is 1.1W/m^{2}K and the light transmittance is 72%. [8]

11.1.4 Walls, floor and ceiling

The walls of the experimental rooms are covered with light grey wallpaper, which is an almost perfectly diffusing surface. The ceiling is made of white suspended ceiling tiles and the floor is covered with a dark grey carpet. The reflectance values for the different surfaces are presented in **Table 11.1**. [8]

Table 11.1 - Reflectance values for the walls, ceiling and floor of the experimental rooms

Surface	Reflectance
Walls	62%
Ceiling	88%
Floor	11%

11.1.5 The furniture

The experimental rooms are furnished with two tables each. The tables size is 0.75m by 1.5m and they are centred with respect to lateral walls. The first one is 0.64m offset from the window, while the second is 1.0m offset from the first one. The top of the tables is 0.85m offset from the floor. The reflectance of the tables is 80% (see **Figure 11.4**).

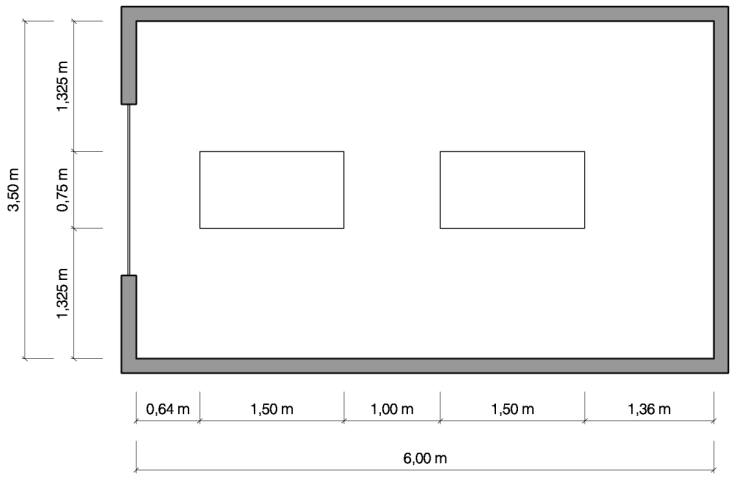

Figure 11.4 - Position of the tables inside the experimental rooms

11.1.6 The glass lamellas system

As it was stated before, the only difference between both experimental rooms is that one of them (named the Test room throughout this dissertation) is equipped with a glass lamellas system on the exterior side of its façade while the other (named the Reference room) does not have the glass lamellas system mounted on its façade. (The purpose of the measurements was to evaluate the influence of the glass lamellas shading system on the daylight level inside the rooms.)

The glass lamellas system is composed of five glass lamellas which are supported by horizontal metallic profiles along their length. The horizontal metallic profiles are supported on their extremes by two vertical lateral profiles. (see **Figure 11.5**) The horizontal profiles can move up and down along the vertical profiles and they are able to rotate so the orientation of the lamellas can be changed. For the measurements the axis of rotation of the lower lamella was set 0.9m offset from the floor of the room and approximately 0.30m from the glazing. The distance between two consecutive lamellas is 0.5m.

Each lamella is 2.95m long, 0.5m wide and 8mm thick.

The glass used is Antelio Silver from Saint Gobain Glass. The visual transmittance of the glass is 66% and the visual reflectance 31%.

The section of the horizontal metallic profiles in which the lamellas are supported is 8cm high, 6cm wide in the largest part and 2.5cm wide in the narrowest part (see **Figure 11.6**). However due to

lack of information in the beginning of the simulations it was modelled as 8cm high by 6cm wide in the largest part and 4cm wide in the narrowest part (see **Figure 11.7**). However, it was assumed that this difference is not significant on the indoor daylight values.

Figure 11.5 - Picture of the glass lamellas system mounted on the façade of the Test room

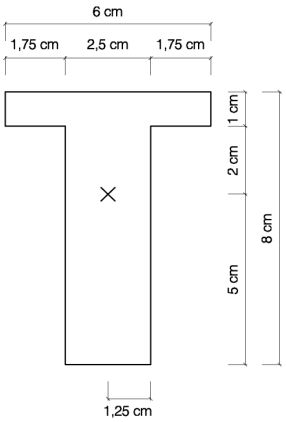

Figure 11.6 - Real section of the horizontal metallic profiles in which the glass lamellas are supported

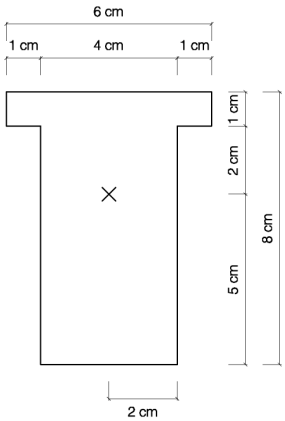

Figure 11.7 - Section of the horizontal metallic profiles in which the glass lamellas are supported as they were modelled in *IESve*

11.2 Measuring conditions

The illuminance values were measured with lux meters located in different points of the working plane (0.85m high) and ceiling of the experimental rooms. The measuring points, the same for the Test and Reference rooms and are represented in **Figure 11.8** and **Figure 11.9**.

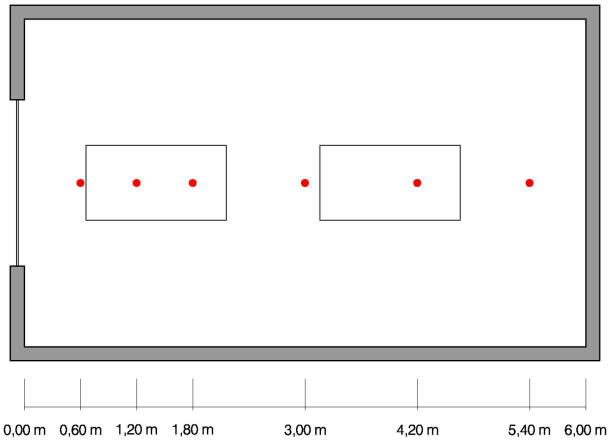

Figure 11.8 - Plan of the Test room/Reference room with the location of the measuring points

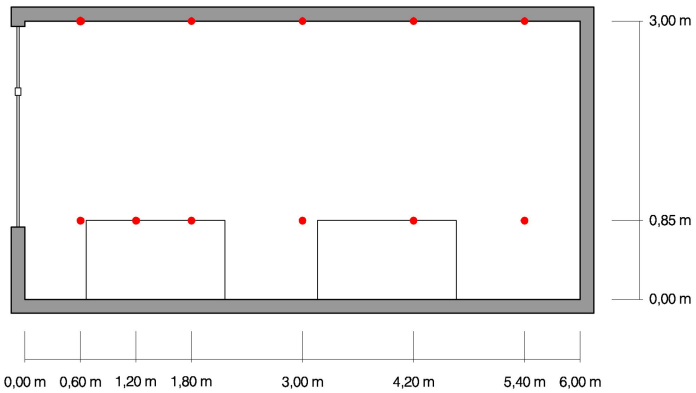

Figure 11.9 - Section of the Test room/Reference room with the location of the measuring points

The measurements were performed for four different cases which correspond to different sky conditions and glass lamellas positions of the Test room (see **Figure 11.10**). For each case measurements of the Test room and Reference room were performed simultaneously so the influence of the lamellas could be assessed.

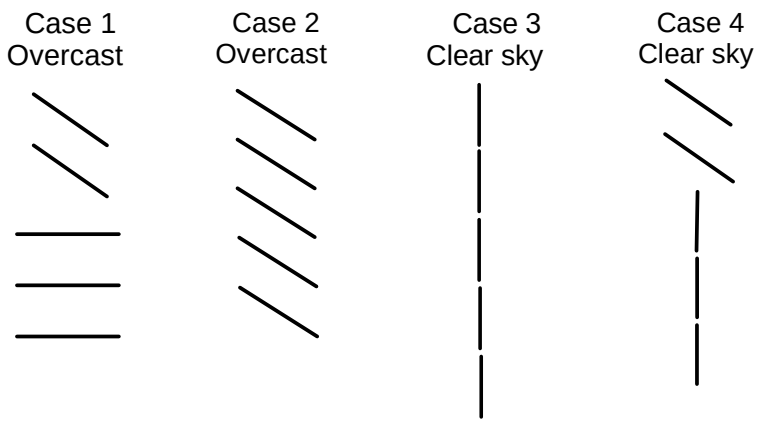

Figure 11.10 - Case studies: sky conditions and position of the glass lamellas for the Test room

11.2.1 Case 1

Case 1 corresponds to an overcast situation: the upper two lamellas were set in the 30º position while the others were opened.

For this case the daylight factor was determined for all the measuring points in the working plane and ceiling represented in **Figure 11.8** and **Figure 11.9**. Around 300 measurements were performed under overcast skies and the average and standard deviation were calculated for each measuring point.

The overcast factor, which is the ratio between the vertical and horizontal illuminances (E_{vert}/E_{hor}), was calculated for each measurement and the results compared with the overcast factor for the CIE overcast sky (0.396). The results obtained for the overcast factors are presented in **Figure 11.11**: all the values are inside the range [0.38;0.42] but most part of them are higher than the CIE overcast sky which means that during the measurements the distribution of the sky is slightly different from the one the characterizes the CIE overcast sky.

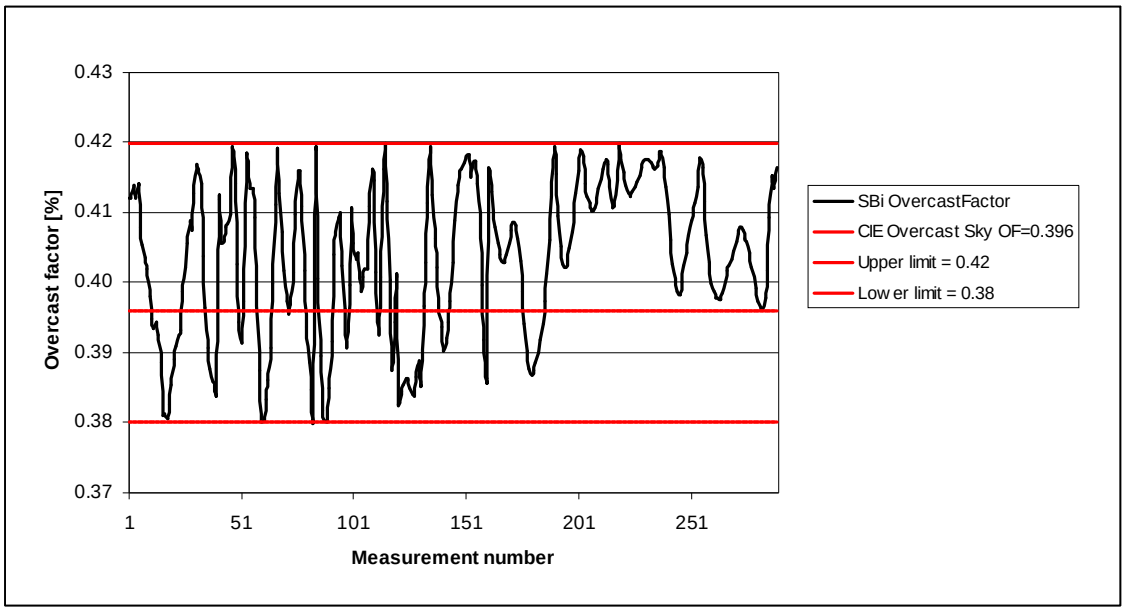

Figure 11.11 - Overcast factor for the measurements performed for Case 1

11.2.2 Case 2

Case 2 is similar to Case 1. Only the position of the lamellas is different: all the lamellas are set with an angle of 30º.

Also around 300 measurements under overcast skies were performed in order to obtain the daylight factors for all the measuring points represented in **Figure 11.8** and **Figure 11.9**.

The overcast factors during the measurements are presented in **Figure 11.12**. Once again in most measurements the overcast factor was higher than the one for the CIE overcast sky.

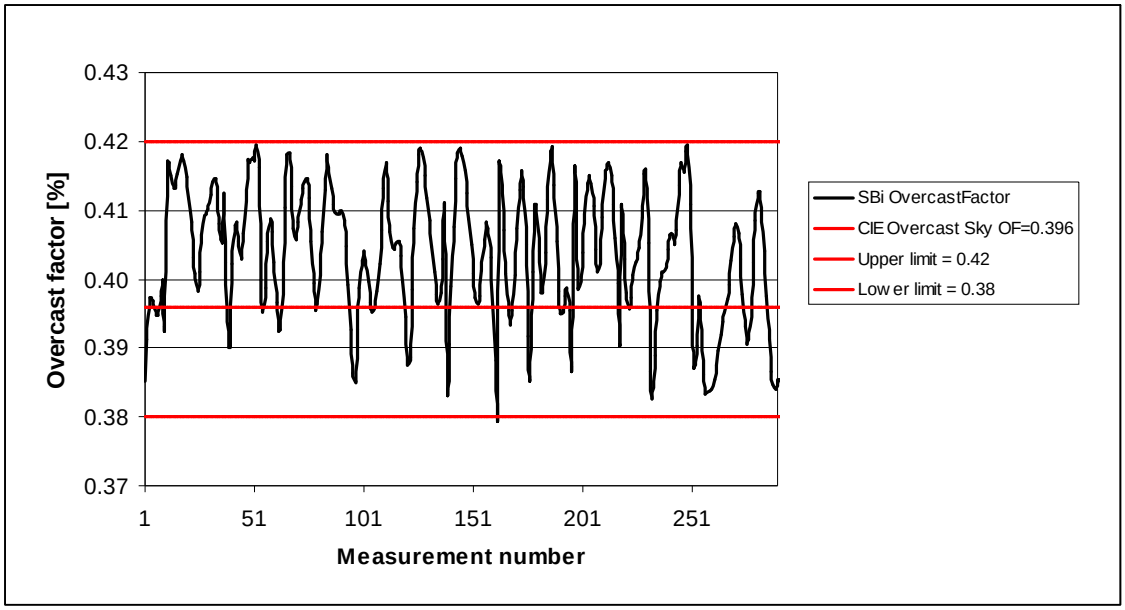

Figure 11.12 - Overcast factor for the measurements performed for Case 2.

11.2.3 Case 3

Case 3 corresponds to the situation in which all the lamellas are closed.

During a day of clear sky with full sun (May 3rd 2007), the illuminance was measured for the working plane points represented in **Figure 11.8**. The measurements were registered every 30 seconds during whole the day, but only three instants of the day were chosen for this study. The chosen times are 10.07 (morning), 13.07 (noon) and 16.07 (afternoon).

The global (horizontal) illuminance measured on the roof was 62608 lux at 10.07, 76779 lux at 13.07 and 62631 lux at 16.07.

11.2.4 Case 4

In Case 4 the two upper lamellas are opened to 30º while the others are closed.

During a day of clear sky with sun but with some periods of white clouds (May 18th 2007), the illuminance was measured for the working plane points represented in **Figure 11.8**. The measurements were registered every 30 seconds during whole the day, but only three instants of the day were chosen for this study. The chosen times are 10.07 (morning), 13.07 (noon) and 16.07 (afternoon).

The global (horizontal) illuminance measured on the roof was 67444 lux at 10.07, 82670 lux at 13.07 and 67392 lux at 16.07.

12. Modelling in *IESve/Radiance*

12.1 The method

Radiance uses a ray-tracing method to generate virtual images of the scenes (see **APPENDIX G**). In these images the daylight levels can be read. As shown in **Figure 12.1**, the rays are randomly send from the focus of a virtual eye and reflected on the surfaces until they intersect a light source or until the ray has reflected more than a specified number.

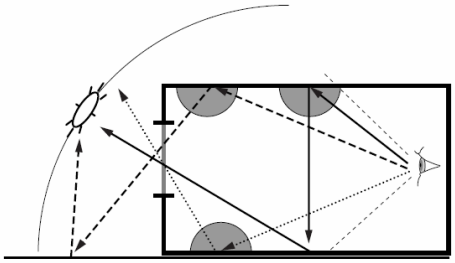

Figure 12.1 - Raytracing method used in Radiance [22]

12.2 Settings and assumptions

12.2.1 The model

The model of the experimental rooms was built in *IESve* according to the description previously made of the experimental rooms (see **Figure 12.2** and **Figure 12.3**). The landscape was simply modelled as a field of grass with a length of 20m, the distant row of trees towards south and the group of trees towards the south-west direction were neglected.
(The model of the test room for the different Cases: 1, 2, 3 and 4 is presented in **APPENDIX F**)

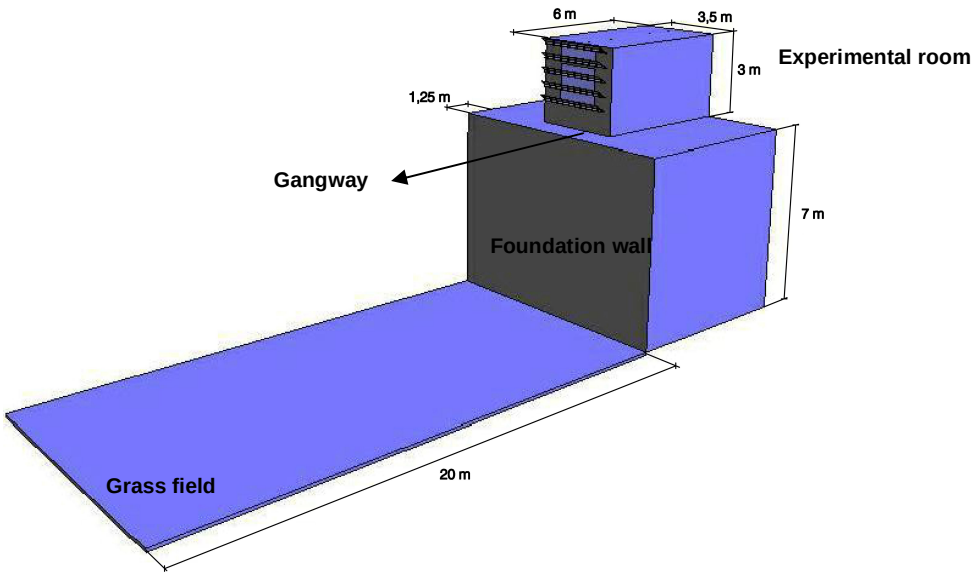

Figure 12.2 - Model of the experimental rooms built in *IESve*

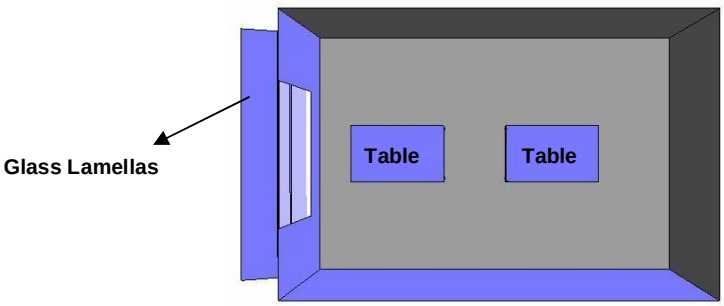

Figure 12.3 - Interior of the experimental rooms modelled in *IESve*

Auxiliary solids located in the measuring points were created to make possible the reading of the illuminance and daylight factor levels in the images generated by *IESve/Radiance*. These auxiliary solids are cylinders with a diameter of 0.04m and a height of 0.02m and they are represented in **Figure 12.4**. The reflectance of the measuring points was assumed to be 80% (the same reflectance of the tables).

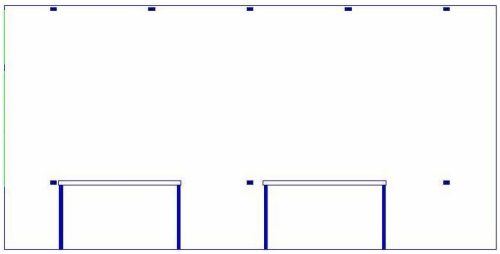

Figure 12.4 - Image of the model in *IESve* showing the auxiliary cylinders created in the measuring points positions

12.2.2 The surfaces properties

In *Radiance* there are different types of materials according to the way the surfaces perform when exposed to light: *plastic*, *metal*, *glass*, *dielectric* and *trans*. [13]
Excluding the windows glazings which were defined as *glass* and the glass lamellas which were defined as *trans*, all the other surfaces in the model were defined as *plastic*.

12.2.2.1 *Plastic* Material - All surfaces excluding glazings and glass lamellas

In *Radiance*, *plastic* defines opaque surfaces with uncoloured specular highlights. This type of material is defined by its red, green and blue (RGB) reflectance values and a value for specularity and roughness. The reflectance values vary between 0.0 and 1.0: (0.0,0.0,0.0) defines a black surface while (1.0,1.0,1.0) defines a white surface. The specularity is the amount of light reflected by specular (mirror-like, not diffuse) mechanism. Specularity also varies from 0.0 to 1.0, 0.0 defines a perfectly diffuse surface while 1.0 a perfect mirror. For *plastic* materials the specularity is usually in the range 0.0-0.07. The roughness refers to how the surface scatters the light that is reflected, 0.0 corresponds to a perfectly smooth surface and

a 1.0 would be a very rough surface. Roughness values above 0.2 are unusual. The roughness affects only the specular reflection.

In **Table 12.1**, the RGB reflectances, specularity and roughness for the surfaces modelled as *plastic* material are presented.
All the surfaces excluding the tables (whose appearance is slightly satin) were assumed to be perfectly diffuse. In this case the roughness value is not important since it refers to the specular reflection. The specularity of the tables was assumed to be 0.03 and the roughness was set to 0.00 since the tables are polished.

Table 12.1 - RGB reflectances, specularity and roughness for the surfaces modelled as plastic material

Element	R-refl	G-refl	B-refl	Spec	Rough
Inner walls	0.62	0.62	0.62	0.00	-
Floor	0.11	0.11	0.11	0.00	-
Ceiling	0.88	0.88	0.88	0.00	-
Tables	0.80	0.80	0.80	0.03	0.00
Tables legs	0.60	0.60	0.60	0.00	-
Measuring points	0.80	0.80	0.80	0.00	-
Horizontal metallic profiles of the glass lamellas	0.60	0.60	0.60	0.00	-
Gangway	0.60	0.60	0.60	0.00	-
Foundation wall	0.60	0.60	0.60	0.00	-
Grass (reflectance = 0.20)	0.00	0.30	0.00	0.00	-

12.2.2.2 *Glass* Material - Glazings

As it was stated before the glazings of the windows were modelled as *glass* which is a special case of *dielectric* material with a refraction index of 1.52. A *dielectric* material is transparent, and it refracts light as well as reflecting it.
The *glass* is represented by one single surface which avoids the computation of internal reflections.
The *glass* must be defined by the R, G and B transmissivity values. Transmissivity is the fraction of light not absorbed in one traversal of the material at normal incidence while the transmittance is the total light transmitted through the pane including multiple reflections. The visual transmittance value is the one given by manufactures (which is 72% for the double-pane glazing of the experimental rooms). The visual transmittance is converted in transmissivity through the following formula:

$$tn = \frac{\sqrt{0.8402528435 + 0.0072522239\,Tn^2} - 0.9166530661}{0.003626119\,Tn} \qquad (12.1)$$

where *Tn* represents the transmittance and *tn* the transmissivity. For the glazing of the windows of the experimental rooms the transmissivity is then 0.62. All the components R, G and B are equal to 0.62 since the glazing is clear.

Table 12.2 - RGB transmissivities of the glazings of the experimental rooms

Element	R-tn	G-tn	B-tn
Glazings	0.62	0.62	0.62

12.2.2.3 *Trans* Material - Glass Lamellas

According to [13] the glass lamellas were modelled as *trans* material. *Trans* represents a transparent/translucent material type.

The *trans* materials are defined in *Radiance* by seven parameters: R-reflectance, G-reflectance, B-reflectance, specularity, roughness, transmissivity and transmitted specularity.

The way how *Radiance* handles the encountering of a surface of a *trans* material is described in **Figure 12.5**.

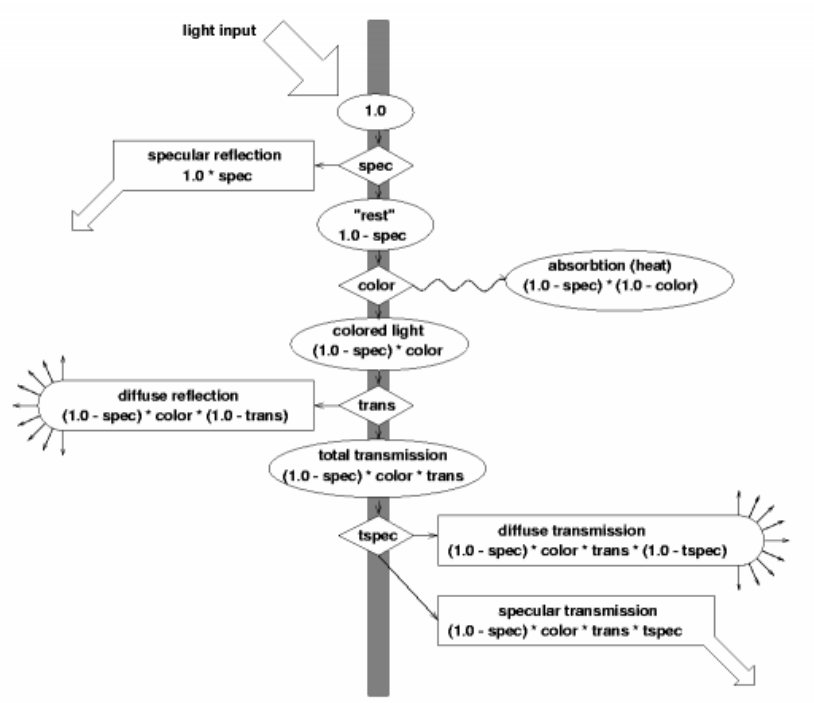

Figure 12.5 - Diagram of how Radiance simulations handle the encountering of a surface of a *trans* material [15]

Knowing the visual reflectance, ρ_v, and visual transmittance, τ_v, of the glass that composes the glass lamellas, it is possible to calculate the seven parameters that characterize the *trans* material according to [13]. As stated before the lamellas are made of Antelio Silver glass from Saint Gobain. For this glass the visual transmittance, τ_v, is 66% while the visual reflectance, ρ_v, is 31%.

The specularity, *spec*, is the fraction of incident light that is immediately reflected in mirror and it is equal to the visual reflectance (spec=0.31).

The R-reflectance, G-reflectance and B-reflectance are the colour dependent reflectances. As Antelio Silver is a clear glazing these values are all equal and can be represented by RGB-reflectance. The RGB-reflectance may be calculated knowing the visual absorptance of the glass, α_v.

For Antelio Silver the light absorptance, α_v, is:

$$\alpha_v = 1 - 0.66 - 0.31 = 0.03 \quad (12.2)$$

According to **Figure 12.5** the RGB-reflectance may be calculated through the following equation:

$$\alpha_v = (1 - spec)(1 - RGBrefl) \quad (12.3)$$

$$0.03 = (1 - 0.31)(1 - RGBrefl) \quad (12.4)$$

$$RGBrefl = 0.96 \quad (12.5)$$

The transmissivity, *transm*, is a factor describing how much of the remaining light is transmitted through the glass. Any remaining light will be reflected diffusely. The transmissivity is calculated by:

$$\tau_v = (1 - spec) \cdot RGBreflec \cdot transm \quad (12.6)$$

$$0.66 = (1 - 0.31) \cdot 0.96 \cdot transm \quad (12.7)$$

$$transm = 1.0 \quad (12.8)$$

The roughness, *rough*, is 0.0 for glass since it has a smooth surface.

The transmitted specularity, *tr-spec*, is an index describing the distribution of the transmitted light that is not diffusely scattered. It is 1.0 for a clear glass.

The *IESve/Radiance* inputs for the Antelio Silver glass lamellas defined as *trans* material are presented in **Table 12.3**.

Table 12.3 - *IESve/Radiance* inputs for Antelio Silver glass lamellas defined as *trans* material

Element	R-refl	G-refl	B-refl	Spec	Rough	Transm	Tr-spec
Antelio Silver Glass Lamellas	0.96	0.96	0.96	0.31	0.0	1.0	1.0

12.2.3 The Sky / Date / Time

For Case 1 and Case 2 the *CIE overcast sky* was chosen for the simulations. The simulations were performed for the 21st of December at 12.00. However the chosen date and time have no influence because the daylight level in the different measuring points was evaluated by the daylight factor.

For Case 3 and Case 4 the option *Sunny sky* was chosen. This corresponds to a completely clear sky with full sun [15]. In these cases, as the daylight level in the different measuring points was evaluated by the illuminance [lux], the global (horizontal) illuminance for each simulation must be determined and compared to the one for the correspondent measurement.
The days and time of the simulations were defined the same as the instants of measurements, taking into account that the measurements occurred during May 3rd and 18th in which the summer time in set. For the simulations the real solar time, which in Denmark is one hour less, had to be set. In **Table 12.4**, the instants of the measurements and the correspondent instants set in the simulations are presented.

Table 12.4 - Table showing the date/time of the measurements for Case 3 and Case 4 and the correspondent date/time set for the *IESve/Radiance* simulations

Case number	**Date/time of the measurement** (summer time)	**Date/time set for the *IESve/Radiance* simulation** (real solar time)
Case 3	May 3rd, 10.07	May 3rd, 09.07
	May 3rd, 13.07	May 3rd, 12.07
	May 3rd, 16.07	May 3rd, 15.07
Case 4	May 18th, 10.07	May 18th, 09.07
	May 18th, 13.07	May 18th, 12.07
	May 18th, 16.07	May 18th, 15.07

12.2.4 Image quality

The rendering options are a group of different parameters that can be adjusted to guarantee the accuracy of the image generated by *IESve/Radiance*. The optimal rendering option settings are the ones that provide the highest possible accuracy in an acceptable rendering time. More information about the rendering options is available in [5] and [15].
For the *IESve/Radiance* simulations performed for this dissertation the rendering options set are presented in **Figure 12.6**.

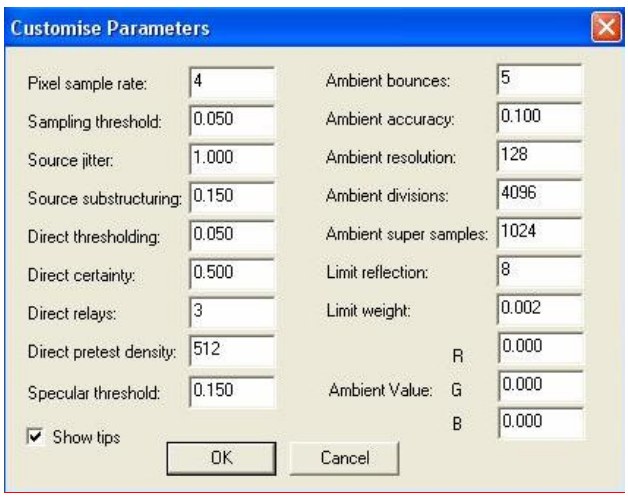

Figure 12.6 - Rendering options set for the *IESve/Radiance* simulations performed for the experimental rooms of the Daylight Laboratory at SBi

13. Results and Comparison with the measurements

In this chapter the results from the measurements performed in the experimental rooms of the Daylight Laboratory at SBi, as well as the correspondent results from the *IESve/Radiance* simulations are presented for the four cases described before. Only the most relevant results are presented.

13.1 Case 1

13.1.1 The reference room

13.1.1.1 The working plane

In **Table 13.1** the SBi measurements and *IESve/Radiance* results for the daylight level at the working plane (height=0.85m) are presented for the reference room (without glass lamellas) under overcast sky. The daylight levels are presented as daylight factors, DLfactor [%].
For the measurements also the standard deviation, Stdev, is presented.
In the last column of the table it is presented the relative difference, [%], between the results from the *IESve/Radiance* simulations and the measurements. The relative difference, RD, was calculated in the following way:

$$RD = \frac{DLfactor_{IESve\ /\ Radiance} - DLfactor_{Measurement}}{DLfactor_{Measurement}} \quad (13.1)$$

Table 13.1 - Daylight factors at the working plane for the reference room for Case 1: measurements and *IESve/Radiance* simulations

Distance from window (m)	Measurements		IESve/Radiance	Relative Diference [%]
[m]	DL factor [%]	Stdev	DL factor [%]	
0.6	**17.5**	4.03	**18.6**	6.3
1.2	**9.8**	2.34	**10.3**	5.1
1.8	**6.8**	1.82	**6.1**	-10.3
3.0	**3.1**	1.13	**2.6**	-16.1
4.2	**2.1**	0.89	**1.4**	-33.3
5.4	**1.5**	0.73	**1.0**	-33.3

The results from *IESve/Radiance* are relatively close to the measurements especially near the window. Near the back wall the results from the simulations are around 30% lower than the measurements. However, despite this difference, **Figure 13.1** shows that all the results from the simulations are inside the ranges defined by the measurements and correspondent standard deviations.

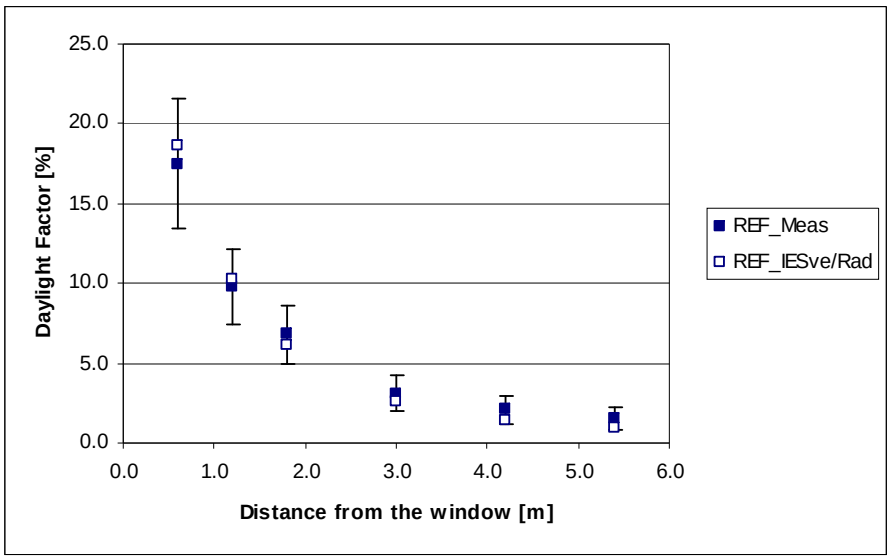

Figure 13.1 - Measured and simulated daylight factors for the working plane in the reference room for Case1. The standard deviation is visible for each measurement.

Indeed, since the distant row of trees in the horizon was not modelled, it would be expected higher daylight levels from the simulations than from the measurements, especially in the back part of the room. The mentioned row of trees obstructs the lower part of the sky reducing the incident light in the back of the room. However this phenomenon is not visible when comparing the results with the simulations.

While the part of the room near the window receives mainly directly light from the sky and from outside reflections, most of the light arriving to the back part of the room is a result of consecutive reflections on the different surfaces of the room (see **Figure 13.2**). For this reason, if the *Radiance* rendering options are not correctly set when performing simulations the results can be not accurate especially at the back part of the room. However different rendering options were tested (including the number of bounces which was increased from 5 to 8) and no better results were achieved.

Another reason for lower daylight factors in the back part of the room when comparing simulations with measurements could be a sub-estimation of the reflectances of the inner surfaces of the room. As described before most part of the light reaching the back of the room is due to reflections. If the reflectances of the inner surfaces are not correctly modelled, the daylight factor at the back part of the room can be influenced. To evaluate this influence, a simulation was performed increasing 5% the reflectance of the following surfaces: inner walls, floor, ceiling and tables. In **Table 13.2** the new reflectances are presented. The results are presented in **Table 13.3**. The relative difference is the back part of the room decreased from around 30% to 20% which is significant but still can not explain all the difference between simulations and measurements.

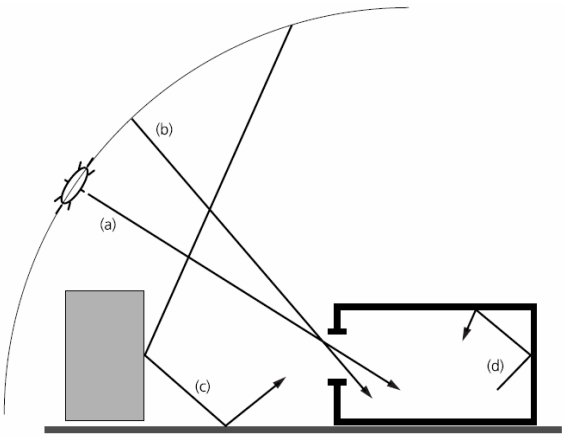

Figure 13.2 - Components of daylight: (a) direct sun, (b) direct sky, (c) externally reflected, and (d) internally reflected [22]

Table 13.2 - Reflectances defined in the *IESve/Radiance* model and new reflectances used to evaluate the influence of the internal surfaces reflectances in the daylight factor in the back part of the room

Element	Reflectances defined in the model	New reflectances
Inner walls	0.62	0.67
Floor	0.11	0.16
Ceiling	0.88	0.93
Tables	0.80	0.85

Table 13.3 - Daylight factors at the working plane in the reference room for Case 1. Results obtained from *IESve/Radiance* simulations when increasing 5% the reflectance of the internal surfaces

IESve/Radiance DL factor [%]	Relative Diference [%]
18.4	5.1
10.6	8.2
6.4	-5.9
2.9	-6.5
1.6	-23.8
1.2	-20.0

Another reason for different *IESve/Radiance* results and measurements may be the sky. The real overcast sky is never equal to the CIE overcast sky defined by the standards and used for daylight simulations.

13.1.1.2 The ceiling

In **Table 13.4** the SBi measurements and *IESve/Radiance* results for the daylight factor, DLfactor [%], at the ceiling are presented for the reference room (without glass lamellas) under overcast sky. (see comments above **Table 13.1** for better understanding)

Table 13.4 - Daylight factors at the ceiling for the reference room for Case 1: measurements and *IESve/Radiance* simulations

Distance from window (m)	Measurements		IESve/Radiance	Relative Diference [%]
[m]	DL factor [%]	Stdev	DL factor [%]	
0.6	**4.3**	0.336	**4.5**	4.7
1.8	**2.3**	0.175	**2.6**	13.0
3.0	**1.5**	0.075	**1.4**	-6.7
4.2	**1.1**	0.048	**0.9**	-18.2
5.4	**0.8**	0.040	**0.7**	-12.5

As for the working plane the results from simulations are higher than the measurements near the window and lower in the back part of the room. However the relative difference between the simulations and measurements in the back part of the room is lower than for the working plane.

Opposite to the simulations results for the working plane, the simulations results for the ceiling do not fit so well in the ranges defined by the measurements and correspondent standard deviations. The standard deviation values are lower. Anyway the results are quite close to the measurements. (see **Figure 13.3**)

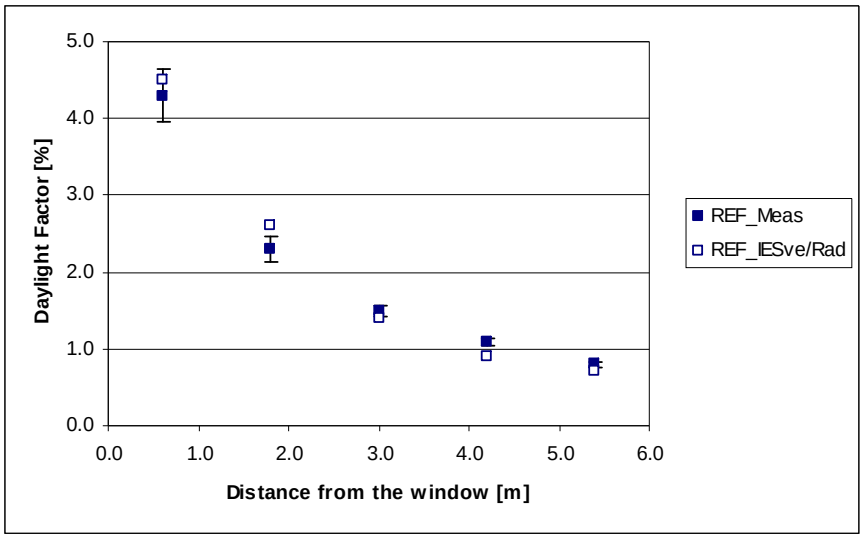

Figure 13.3 - Measured and simulated daylight factors at the ceiling in the reference room for Case1. The standard deviation is visible for each measurement

13.1.2 The test room

13.1.2.1 The working plane

In **Table 13.5** the SBi measurements and *IESve/Radiance* results for the daylight factor, DL factor [%], at the working plane (height=0.85m) are presented for the test room (room with glass lamellas) for Case 1.

Table 13.5 - Daylight factors at the working plane for the test room for Case 1: measurements and *IESve/Radiance* simulations

Distance from window (m)	Measurements		IESve/Radiance	Relative Diference [%]
[m]	DL factor [%]	Stdev	DL factor [%]	
0.6	**12.2**	3.36	**10.3**	-15.6
1.2	**7.8**	2.08	**7.5**	-3.8
1.8	**6.1**	1.78	**5.2**	-14.8
3.0	**3.0**	1.04	**2.6**	-13.3
4.2	**1.9**	0.76	**1.4**	-26.3
5.4	**1.5**	0.65	**1.0**	-33.3

Figure 13.4 shows once again the results from *IESve/Radiance* simulations are inside the range defined by the measurements and correspondent standard deviations.

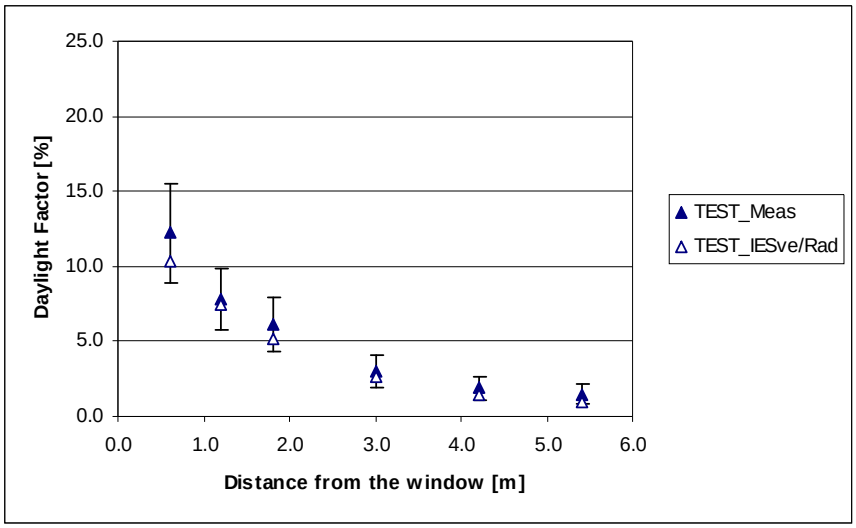

Figure 13.4 - Measured and simulated daylight factors for the working plane in the test room for Case1. The standard deviation is visible for each measurement.

Table 13.5 and **Figure 13.4** show that for the test room the daylight factors obtained with *IESve/Radiance* simulations are lower than the measurements. This would be expected since the daylight factors for the reference room were already lower for simulations than for the measurements.

The important thing is that the performance of the glass lamellas is similar when comparing measurements with *IESve/Radiance* simulations. Both for the measurements and simulations the glass lamellas decreased the daylight factor at the working plane close to the window. Also for both cases (measurements and simulations) the daylight factor at the working plane in the back of the room is the same with or without lamellas. This is one of the advantages of the glass lamellas sytems, they allow homogenising the daylight factor along the depth of the room. (see **Figure 13.5**)

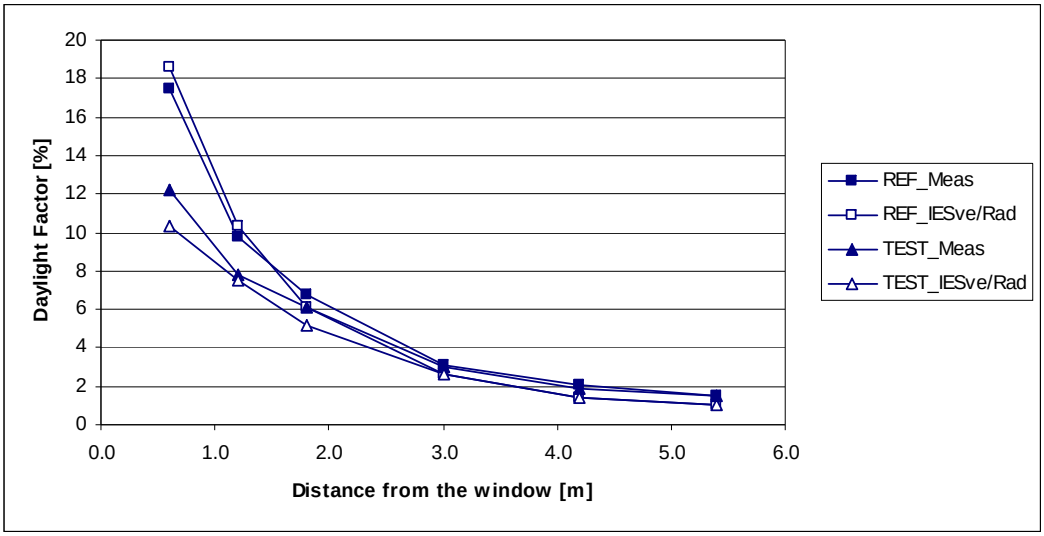

Figure 13.5 - Measured and simulated daylight factors for the working plane for Case 1 for both reference and test room

13.1.2.2 The ceiling

In **Table 13.6** the SBi measurements and *IESve/Radiance* results for the daylight factor, DL factor [%], at the ceiling are presented for the test room (without glass lamellas) under overcast sky. (see comments above **Table 13.1** for better understanding)

Table 13.6 - Daylight factors at the ceiling for the test room for Case 1: measurements and *IESve/Radiance* simulations

Distance from window (m)	Measurements		IESve/Radiance	Relative Diference [%]
[m]	DL factor [%]	Stdev	DL factor [%]	
0.6	**6.0**	0.251	**7.6**	26.7
1.8	**2.4**	0.089	**3.1**	29.2
3.0	**1.6**	0.050	**1.5**	-6.3
4.2	**1.2**	0.032	**0.9**	-25.0
5.4	**0.9**	0.027	**0.6**	-33.3

For this case also the daylight factor at the ceiling in the back of the room is higher for the measurements than for the *IESve/Radiance* simulations.

Once again the performance of the lamellas according to the measurements and *IESve/Radiance* simulations is similar. For the lamellas tilted for Case 1, the daylight factor increases at the ceiling near the window while almost no influence is seen near the back wall. (see **Figure 13.6**)

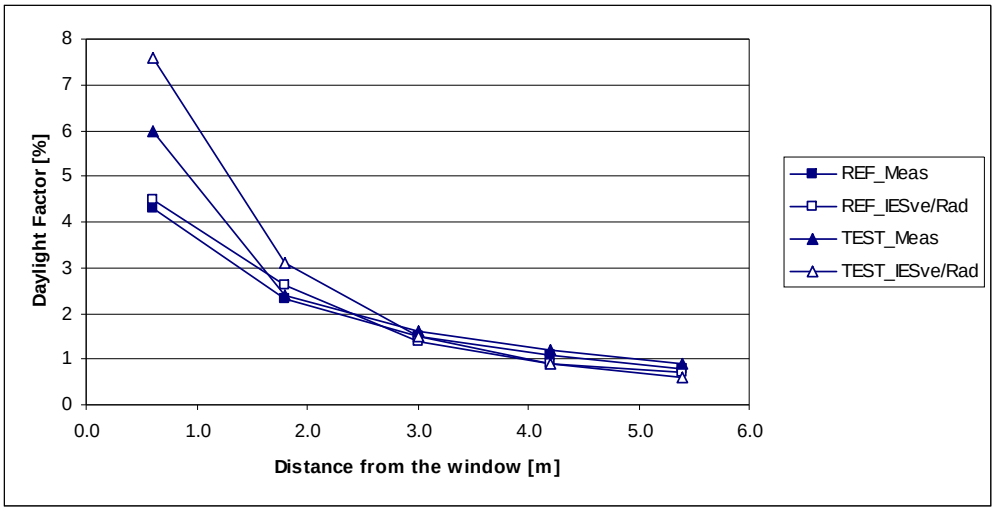

Figure 13.6 - Measured and simulated daylight factors for the ceiling for Case 1 for both reference and test rooms

13.2 Case 2

Case 2 is similar to Case 1, only the orientation of the lamellas is different: they are all tilted to the 30º position. The relation between the measurements and *IESve/Radiance* simulations is also similar to Case 1 and the comments made before are also valid for this case. The results for Case 2 are only briefly presented for the working plane as graphs in **Figures 13.7**, **13.8**, **13.9** and **13.10**.

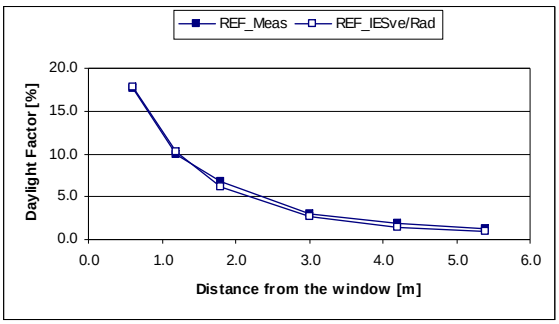

Figure 13.7 - Measurements and simulations at the working plane for the reference room for Case 2

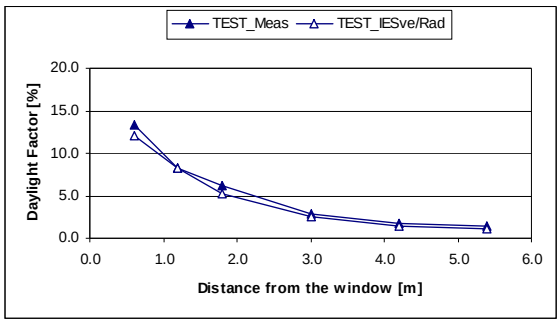

Figure 13.9 - Measurements and simulations at the working plane for the test room for Case 2

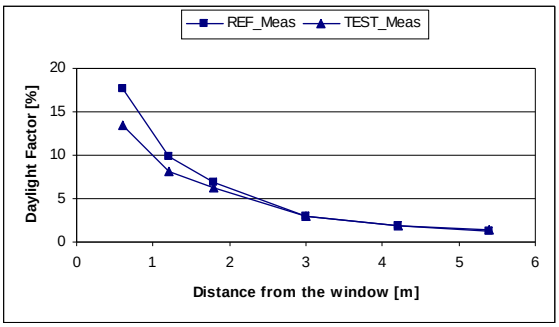

Figure 13.8 - Measurements at the working plane for both reference and test rooms for Case 2

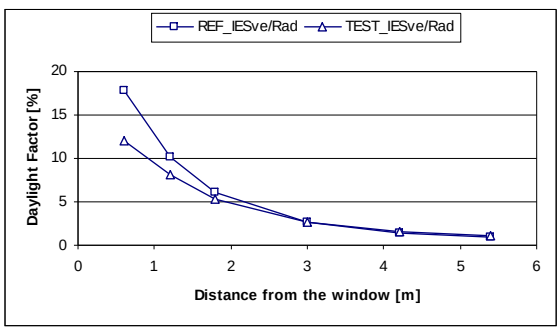

Figure 13.10 - Simulations at the working plane for both reference and test rooms for Case 2

Figures 13.7 and **13.9** show that once again the daylight factors obtained from *IESve/Radiance* simulations are slightly lower than the ones measured, especially in the back part of the room.

Figures 13.8 and **13.10** show that according to both measurements and simulations the glass lamellas allow the homogenization of daylight factor inside the room reducing it near the window. Close to the back wall, both measurements and simulations registered an increase of 0.1% in daylight factor at 5.4m from the window: this improvement is not perceptible in the **Figures 13.8** and **13.10**.

13.3 Case 3

For Case 3 which corresponds to sunny sky the comparison between the measurements and simulations can not be directly done. The indoor daylight was evaluated by the illuminance values at the working plane (height=0.85) and of course it depends on the luminance level of the sky which is different for the real and modelled skies. In this way, a parameter similar to "daylight factor" was defined. This parameter named "daylight factor for sunny sky", DFfactorSS [%], through this dissertation allows an easier comparison between measurements and simulations. The difference between DFfactor and DFfactorSS is that the first one only takes into account diffuse light (which is valid for overcast skies), while the second also takes into account the direct light.

In **Figure 13.11**, the "daylight factors for sunny sky" at the working plane in both reference and test rooms are presented for measurements and simulations. The values refer to May 3rd at 10.07. The results for 13.07 and 16.07 of the same day are not presented. However, for the three different instants of the day the relation between measurements and simulations and the use and non use of lamellas is similar, apart from a small difference presented further in chapter **13.3.1 Comparing 10.07 to 16.07.**

In **Figure 13.12**, the relative difference between "daylight factors for sunny sky" from *ISEve/Radiance* simulations and measurements is presented for the reference room. The values refer to May 3rd at 10.07. The relative difference was calculated in the same basis as the relative differences for daylight factors previously described:

$$RD = \frac{DLfactorSS_{IESve\ /\ Radiance} - DLfactorSS_{Measurement}}{DLfactorSS_{Measurement}} \qquad (13.2)$$

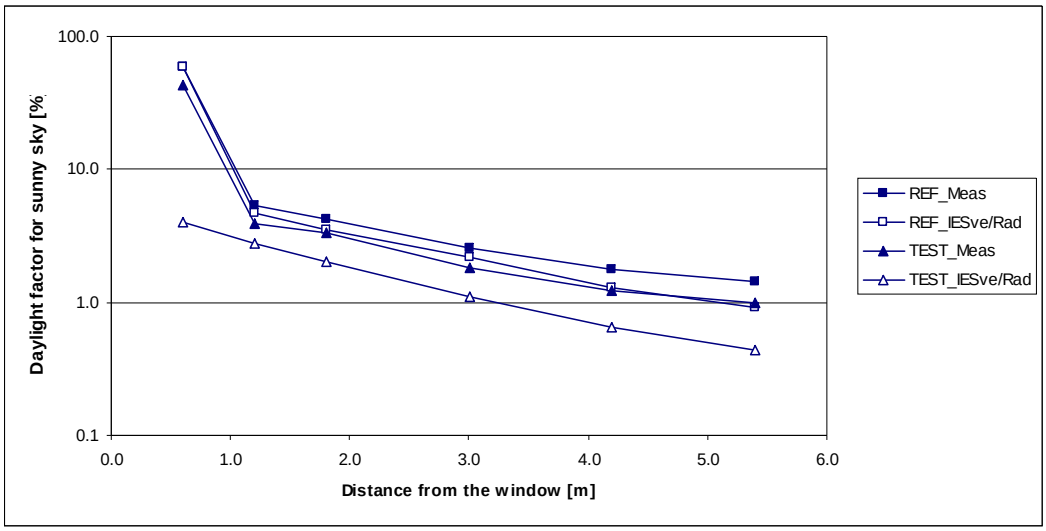

Figure 13.11 - Measured and simulated "daylight factor for sunny sky" at the working plane for both reference and test rooms for Case 3. The values refer to May 3rd at 10.07.

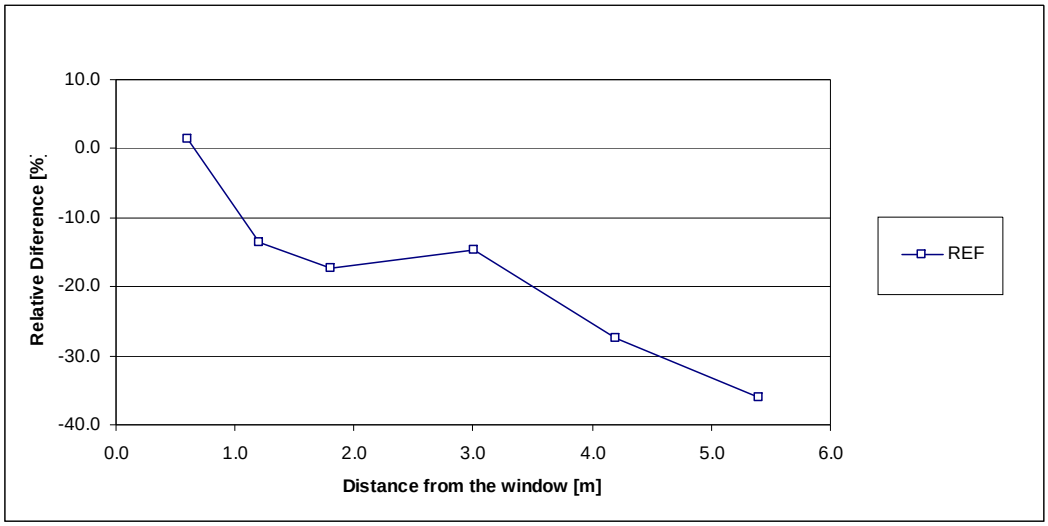

Figure 13.12 - Relative difference between the measured and simulated "daylight factor for sunny sky" at the working plane for the reference room for Case 3. The values refer to May 3rd at 10.07.

Figure 13.11 shows that closer to the window the "daylight factor for sunny sky" at the working plane is very high comparing to the values deeper in the room. This is due to the incidence of direct sun in the room close to the window. In order to represent the daylight levels for all the measuring points the logarithmic scale was chosen for the "daylight factor for sunny sky" axis.

Figure 13.12 illustrates that for the reference room the results from *IESve/Radiance* simulations are slightly lower than the measurements especially in the back part of the room. This would be expected as it also happened with Cases 1 and 2. Similar to Case 1 and 2, in the back part of the room the values from simulations are around 35% lower than the simulations. As a consequence, for the test room, the results from *IESve/Radiance* simulations are also lower than the measurements.

As in this case (Case 3) the measurements refer to a single instant (May 3rd at 10.07) it is more difficult to fit measurements with simulations. During the measurements many factors may vary. The sky may not be completely clear with full sun, some clouds may exist. Also the distribution of a real clear sky is not the same as the standard clear sky. Also other factors as the equipment and human errors are inherent to measurements.

The important conclusion is that during sunny days when the glass lamellas are completely closed acting as a solar shading system they reduce slightly the indoor daylight inside the room (see measurements and simulations for reference and test rooms in **Figure 13.11**). However if compared to typical solar shading systems this decrease is insignificant, when completely activated typical solar shading systems may totally block the light to enter into the room.
It is also important to refer that the decrease in daylight caused by the lamellas is similar when comparing measurement with *IESve/Radiance* simulations (see **Figure 13.11** but take into account that the "daylight factor for sunny sky" is represented in logarithmic scale, in this way, at first glance, it may seem that the decrease in daylight caused by the lamellas is higher for *IESve/Radiance* simulations than for measurements).

Note:

In **Figure 13.11**, for the measuring point closest to the window the daylight level for the simulations of the test room is extremely low when compared to the measurements. This is due to a slight difference between *IESve/Radiance* model and reality. As it can be seen in **Figure 13.13**, according to simulations this measuring point (marked with a red circle) does not receive direct light, in opposition to the points that are close to it. On the other hand, the results show that during measurements the referred measuring point was under the influence of direct light.

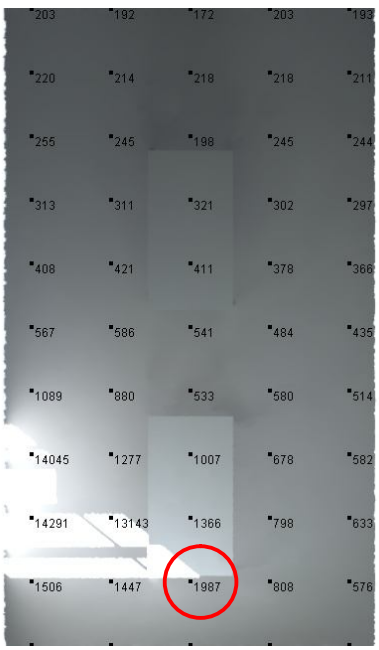

Figure 13.13 - *IESve/Radiance* image. Test room under sunny sky for Case 3 (May 3rd 2007 at 10.07) - Illuminance

13.3.1 Comparing 10.07 to 16.07

In **Figures 13.14** and **13.15**, the "daylight factors for sunny sky" at the working plane in both reference and test rooms are presented for measurements and simulations. **Figure 13.14** refers to May 3rd at 10.07 and **Figure 13.15** to May 3rd at 16.07.

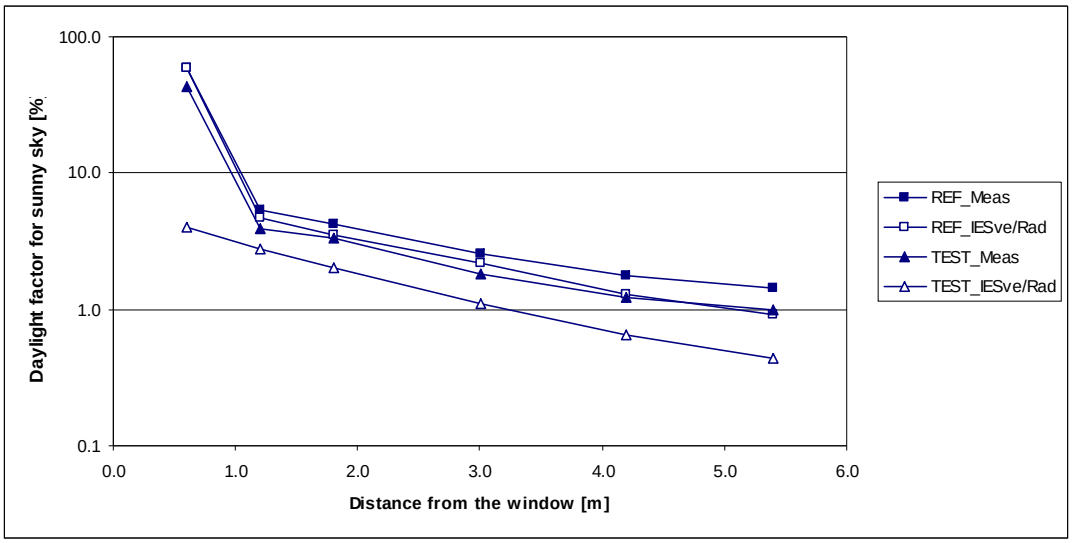

Figure 13.14 - Measured and simulated "daylight factor for sunny sky" at the working plane for both reference and test rooms for Case3. The values refer to May 3rd at 10.07.

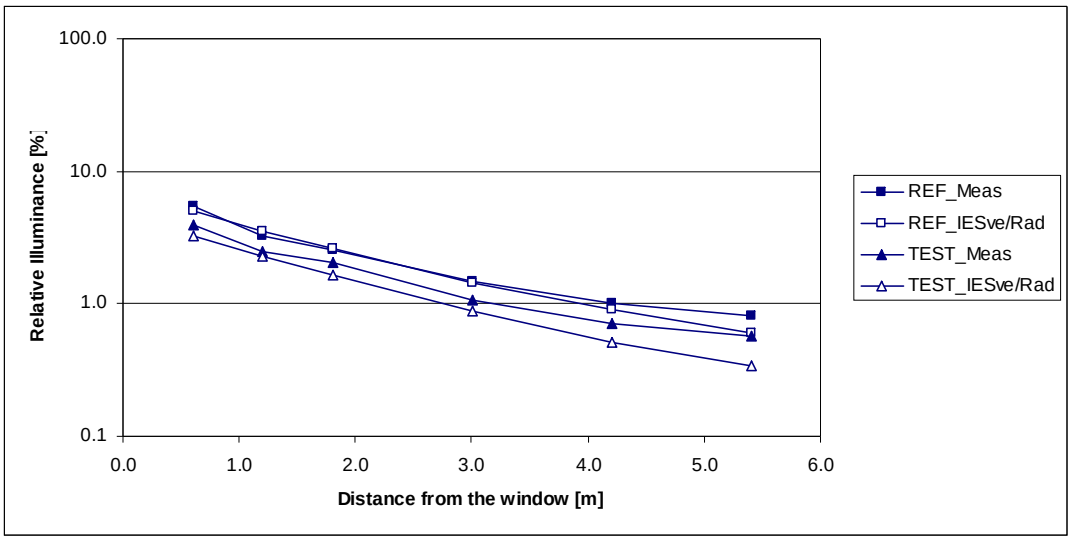

Figure 13.15 - Measured and simulated "daylight factor for sunny sky" at the working plane for both reference and test rooms for Case3. The values refer to May 3rd at 16.07.

Comparing **Figure 13.14** to **Figure 13.15**, it can be seen that the measurements and simulations are closer at 16.07 and at 10.07 especially in the middle of the room.

As referred before there is a constant difference between the measurements and simulations. In the middle and back parts of the room the results from simulations are constantly slightly lower than the measurements.

However at 16.07 the simulations are closer to the measurements. The reason may be the group of trees close to the experimental rooms towards south-west direction that was not modelled. During the afternoon, this group of trees blocks partially the light coming from the sun (see **Figure 11.3** where the view out from the experimental room is shown).

13.4 Case 4

The comments made before for Case 3 are also valid for Case 4 since the results are very similar for both cases.

The main difference is that according to the measurements, for instance at 13.07, the daylight in the back part of the room is higher in the test room than in the reference room. Comparing to Case 3, this means that the two upper lamellas which are set in the 30º position (see **Figure 11.10**) are able to increase the daylight in the back part of the room.
On the other hand, according to the simulations the lamellas are not able to increase the light in the back of the room. Instead they decrease it (see **Figure 13.16**).

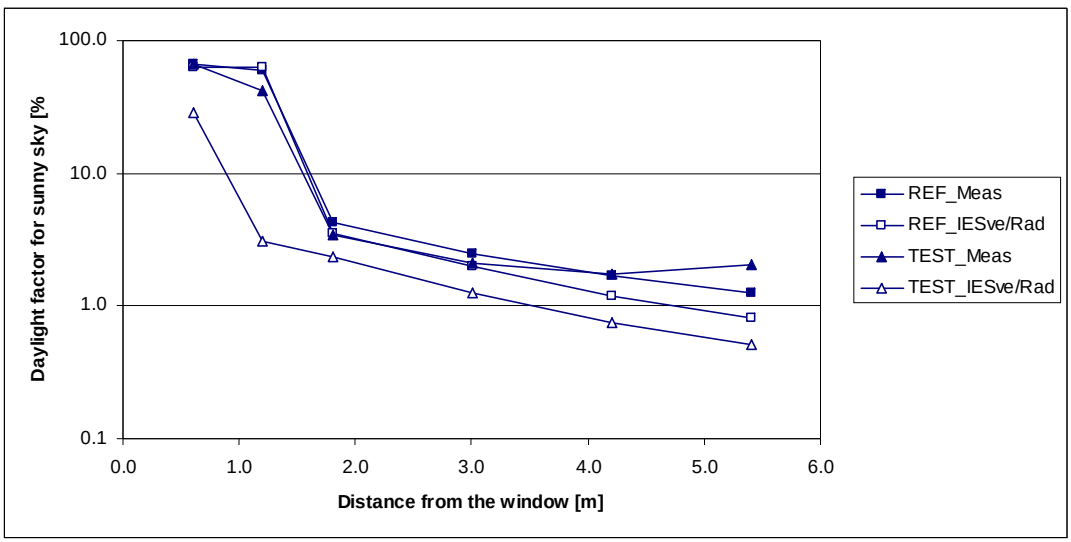

Figure 13.16 - Measured and simulated "daylight factor for sunny sky" at the working plane for both reference and test rooms for Case4. The values refer to May 18th at 13.07.

According to [5], when modelling in *Radiance* rooms in which the windows have complex shading systems (as slat systems) usual simulations do not give accurate results, especially for sunny days in which the amount of light coming into the room is larger and concentrated in one direction. Most

of the light coming through the window from the sun and sky is interreflected by or transmitted through the shading device before coming into the room. In this way, very high accuracy in the indirect calculation options settings is necessary to properly sample and represent the distribution of light coming from the window. This very high accuracy is extremely time consuming and may be not enough.
In the original version of *Radiance* there is a special algorithm “mkillum” that is able to transform surfaces in the room into light sources. In this way, the process can be separated into two parts: first the window is transformed into a light emitter taking into account the light from sun and sky and the effect of the glass lamellas; and after the daylight simulation inside the room is performed without taking into account the exterior environment but only the window as the light emitter [5]. Detailed information about this *Radiance* feature is available in [5] and [22].

This method is much more effective but is not available in *IESve/Radiance*. This can be the reason for the non accordance between simulations and measurements for a sunny sky regarding the effect of the opened glass lamellas in the back part of the room.

Note:
In **Figure 13.16**, for the second measuring point closest to the window the daylight level for the simulations of the test room is extremely low when compared to the measurements. As it happened before with Case 3 (see **Figure 13.11**) this is due to a slight difference between *IESve/Radiance* model and reality. As it can be seen in **Figure G.4** (**Appendix G**), according to simulations the referred measuring point (marked with a red circle) does not receive direct light. This point is on the shadow of one of the horizontal metallic profiles of the glass lamellas system. On the other hand, the results show that during measurements the referred measuring point was under the influence of direct light.

14. Conclusions and further work

Comparing measurements with simulations is always a delicate process even with the most highly developed software. According to [5], *Radiance* is one of the most advanced daylightning/lightning simulation tools available but anyway it can not represent perfectly the “nature”. For instance the distribution of the sky is defined according to standard procedures which are of course not found in reality. Also during measurements many uncontrolled factors may vary.

Daylight measurements in the experimental rooms of the Daylight Laboratory at SBi were compared with *IESve/Radiance* simulations. Four different cases for different sky conditions and lamellas orientation were studied.
IESve/Radiance is a user-friendly software and according to results it seems that it is valid when simulating the daylight performance of glass lamellas systems (as a *trans* material) under overcast sky and also under sunny sky if the lamellas are closed. For simulations under sunny sky and with some lamellas opened it is advised to use the original version of *Radiance* to get more accurate results.

There are two experimental rooms also at DTU and one of them has already a glass lamellas system mounted on its façade. The other will be the reference room.
Some daylight measurements and comparison with *Radiance* simulations are already planned. *IESve/Radiance* may be used for this purpose but also a comparison to the original *Radiance* should be done especially for sunny days with some lamellas opened (extra features available in the original *Radiance* should be used).
It is very important that the characteristics of the room especially the optical properties of the inner surfaces are well determined so they can be modelled closer to reality.
For a better understanding of the differences between measurements and simulations it is advised that the person doing the simulations should also be present during the measurements.

It would be also interesting to evaluate the performance of these glass lamellas systems in real scale buildings located in cities. The evaluation should be done by measurements and software simulations and it would be also important to perform a survey in order to collect people’s experience of the visual comfort.

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APPENDICES

Appendix A - Step-by-step example on how to use *WIS* and *BuildingCalc/LightCalc* for the purpose of this dissertation

A.1 How to obtain the software

A.1.1 *WIS*

WIS is a tool built in *Microsoft Access* and it can be downloaded for free from the website http://www.windat.org [41] where technical support and user instructions are also available.

To assure a complete download of *WIS* the steps next presented should be followed:

1) Download *WIS 3.0.1 setup file*
2) Download *Service Pack 2* (This tool fixes some already detected bugs)
3) Update the Original Database
   3.1) Download *Update Database 2004* and *Update Database October 2006*
   3.2) Import the products from the *Update Databases* to the *Original Database*

Detailed instructions on how to do the referred steps are described on the *WIS* website [41].

A.1.2 *BuildingCalc/LightCalc*

BuildingCalc/LightCalc is a tool being developed in *MATLAB* by the Civil Engineering Department at the Technical University of Denmark (BYG-DTU).
The original *BuildingCalc/LightCalc* runs in MatLab but there is also available a runtime version that does no require *MATLAB*.
The newest version of *BuildingCalc/LightCalc2.3.1f* is not available in the web and but it can be obtained at BYG-DTU (contact Christian Anker Hviid, phD student at BYG-DTU, e-mail address: cah@byg.dtu.dk).

A.2 Step-by-step example

The following example refers to an internal venetian blind applied on the glass façade of the landscaped office building described on the chapter **5.Case study - Landscaped Office Building** of this report.

A.2.1 *WIS* - How to create the text files with the properties of the window

To simulate an internal venetian blind in *BuildingCalc/LightCalc* different text files must be created in *WIS*: one with the properties of the glazing unit without the shading and others with the venetian blind activated for different slat angles.

1) Start *WIS*. (In **Figure A.1** it is presented the *WIS* interface)

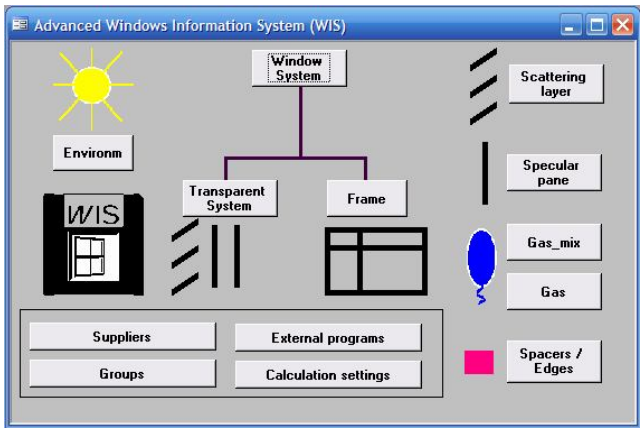


Figure A.1 - *WIS* interface - main window.

2) Click on the *Scattering layer* button. A database with the shading systems available on *WIS* is presented.

3) Click also on the buttons *Specular pane* and *Gas_mix* and see the correspondent available databases. *Specular panes* refers to the glass panes and *Gas_mix* to the gas mixtures that can be used to fill up the gaps between the panes.

4) Return to *WIS* main window and click on the *Transparent System* button.

5) Create a new record setting the different components of the glazing without shading as presented in **Figure A.2**. Each line refers to a different component.
On the first line (that refers to the outer pane) check the box *flip ed*. to flip the pane. *Optitherm SN4* glass has a soft coating surface that must be placed facing the gas gap (see a detailed description in [3], page8).

6) Leave the environment settings as the default option *Te/Ti=0/20 degrees; sun:500* and do not set ventilation in the gas gaps (the gaps between the panes are sealed)

7) Press the *Calculate* button to generate the text file for posterior use in *BuildingCalc/LightCalc*. A window as the one presented in **Figure A.3** will appear. The boxes should be checked as they are in **Figure A.3** otherwise *BuildingCalc/LightCalc* will not be able to read the text file.

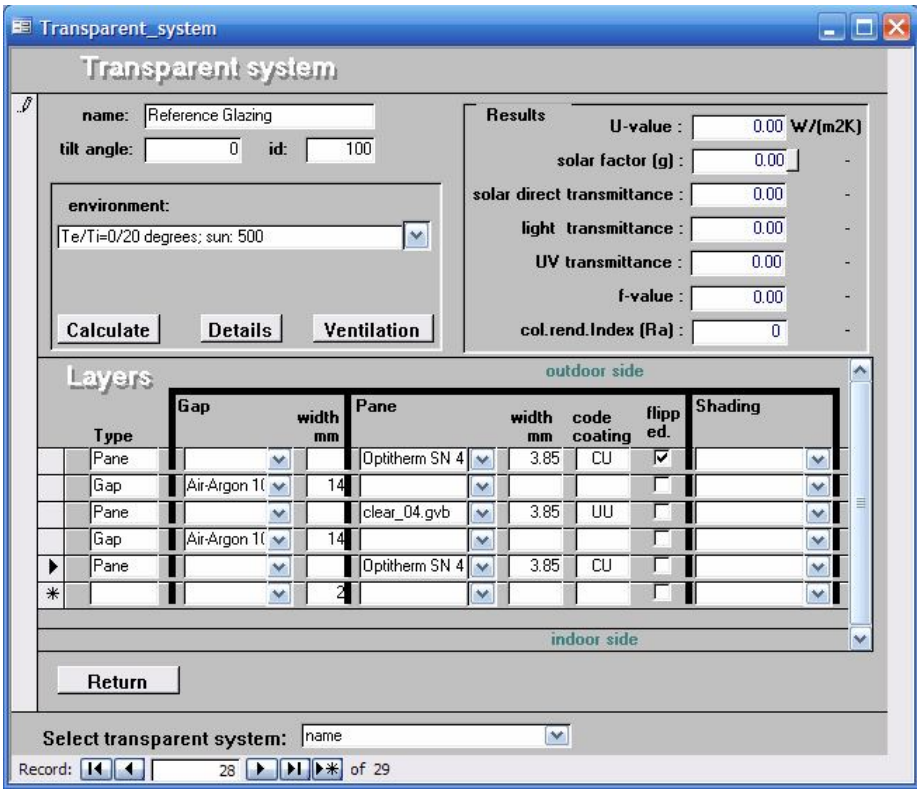


Figure A.2 - *WIS Transparent System* window - *Settings for the glazing*.

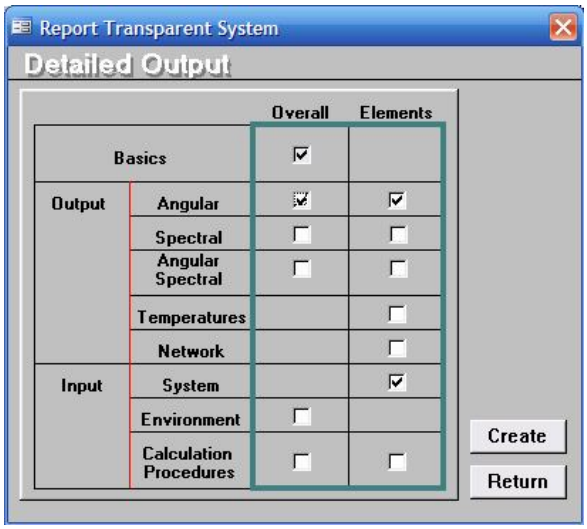


Figure A.3 - *WIS Calculate* window.

8) Click on the button *Create*. A text file with the properties of the glazing will be generated. Name it as *ReferenceGlazing* (for instance) and save it in a known folder: to make easier its posterior use, it is advised to store the *WIS* files in a folder (named for instance *WIS files*) inside the *BuildingCalc/LightCalc* folder.

9) Now that the text file representing the glazing is created, similar text files must be generated for the glazing with the venetian blind (different text files must be created for different slats angles)

Return to the *Transparent System* window and create a new record as presented in **Figure A.4**. Leave an air gap of 50mm between the glazing and the internal venetian blind (do not set ventilation because it is an internal gap). Choose the product *Luxaflex 8%Perforation 2053* as the venetian blind.

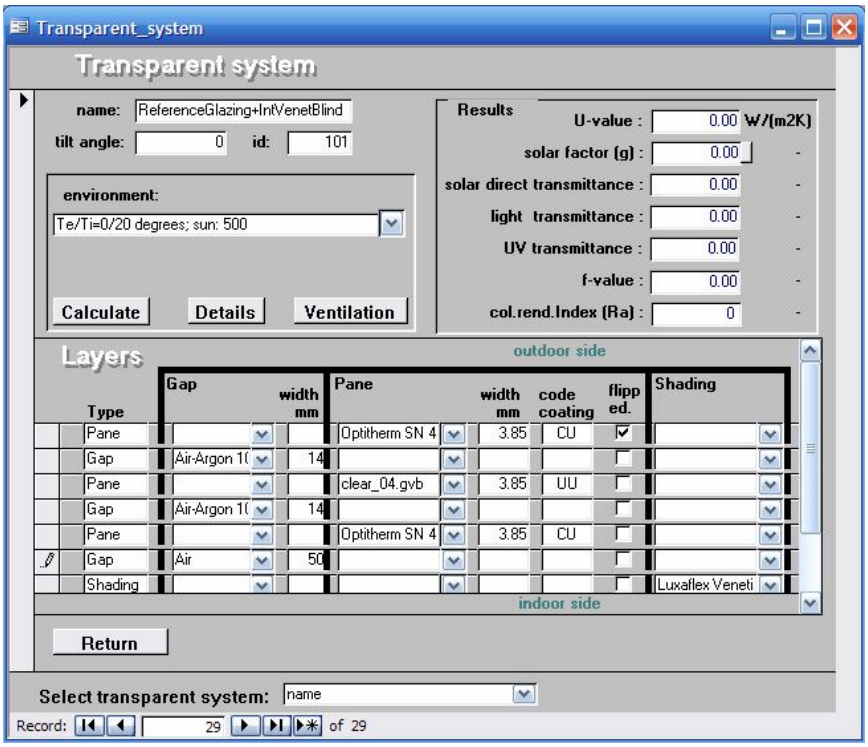


Figure A.4 - *WIS Transparent System* window - *Settings for the glazing + internal venetian blind*

10) Open the *Scattering layer* window and activate the record for the *Luxaflex 8%Perforation 2053*. In the menu *Geometry* set the *slat angle* as -90º (see **Figure A.5**).

11) Click on the button *Calculate*. A new window will appear: answer *Yes*. Next, another window will be presented: click on *Return*.

12) Come back to the *Transparent System* window and press the button *Calculate*. A window as the one in **Figure A.3** will appear: check the boxes as they are checked in **Figure A.3**. Press *Create*.
The text file for the glazing with the internal venation blind with the slats angle of -90º is now created. Save it as *-90.tmp.txt* and store it in a folder named *Luxaflex Venetian Blind 8%Perf 2053* inside the folder *WIS files* referred on 8).

13) Repeat steps 10) to 12) only varying the slats angle. Create text files for the following slats angles: -90º, -80º, -60º, -40º, -20º, 0, 20º, 40º, 60º, 80º, 90º and store them in the folder *Luxaflex 8%Perforation 2053* referred on 12).

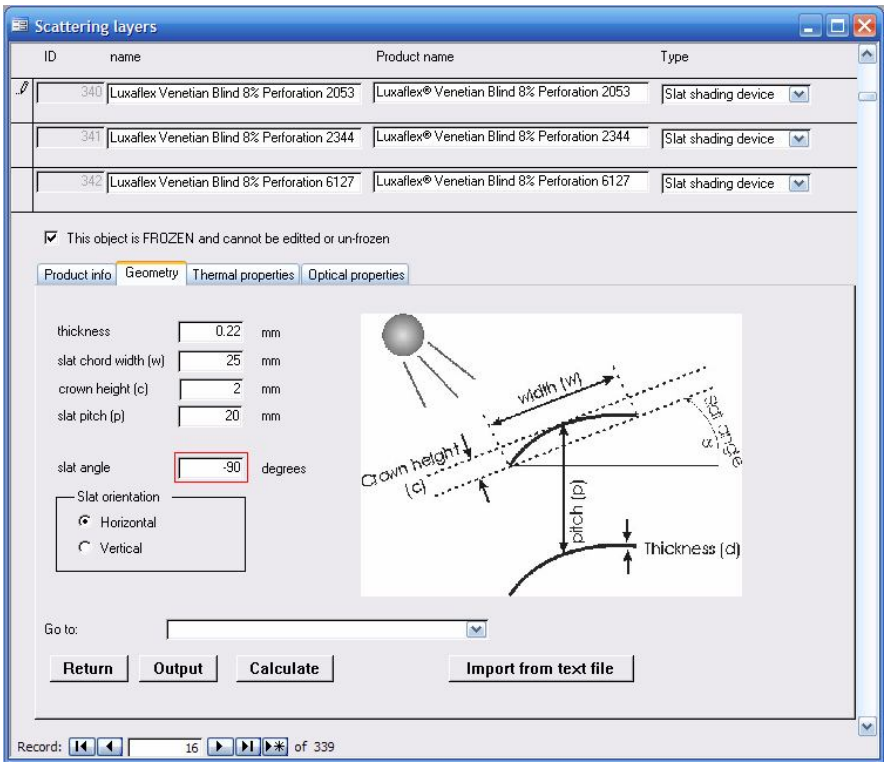
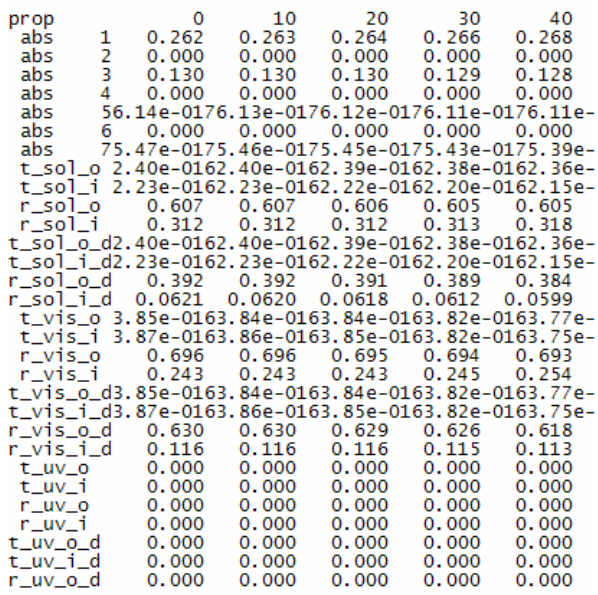


Figure A.5 - *Scattering layer* window - *Luxaflex 8%Perforation 2053* record is activated

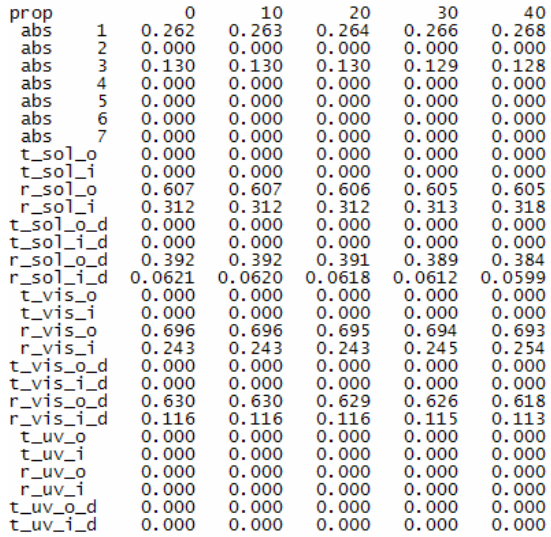
14) Open one by one the text files you created for the different slats angles.
In these text files there is a part (that seems like a large table) where the properties presented are dependent on the incidence angle. Check if these values are well organized in columns. If not round up the numbers to a maximum of 6 digits in order to arrange them back in columns. If this is not done, *BuildingCalc/LightCalc* is not able to read the text files. (See **Figure A.6** and **Figure A.7**)

15) Now the text files with the properties of the glazing without shading and with shading for different slats angle positions are ready to be used in *BuildingCalc/LightCalc*.



```
prop            0      10      20      30      40
 abs    1   0.262   0.263   0.264   0.266   0.268
 abs    2   0.000   0.000   0.000   0.000   0.000
 abs    3   0.130   0.130   0.130   0.129   0.128
 abs    4   0.000   0.000   0.000   0.000   0.000
 abs    56.14e-0176.13e-0176.12e-0176.11e-0176.11e-
 abs    6   0.000   0.000   0.000   0.000   0.000
 abs    75.47e-0175.46e-0175.45e-0175.43e-0175.39e-
 t_sol_o 2.40e-0162.40e-0162.39e-0162.38e-0162.36e-
 t_sol_i 2.23e-0162.23e-0162.22e-0162.20e-0162.15e-
 r_sol_o    0.607   0.607   0.606   0.605   0.605
 r_sol_i    0.312   0.312   0.312   0.313   0.318
t_sol_o_d2.40e-0162.40e-0162.39e-0162.38e-0162.36e-
t_sol_i_d2.23e-0162.23e-0162.22e-0162.20e-0162.15e-
r_sol_o_d   0.392   0.392   0.391   0.389   0.384
r_sol_i_d  0.0621  0.0620  0.0618  0.0612  0.0599
 t_vis_o 3.85e-0163.84e-0163.84e-0163.82e-0163.77e-
 t_vis_i 3.87e-0163.86e-0163.85e-0163.82e-0163.75e-
 r_vis_o    0.696   0.696   0.695   0.694   0.693
 r_vis_i    0.243   0.243   0.243   0.245   0.254
t_vis_o_d3.85e-0163.84e-0163.84e-0163.82e-0163.77e-
t_vis_i_d3.87e-0163.86e-0163.85e-0163.82e-0163.75e-
r_vis_o_d   0.630   0.630   0.629   0.626   0.618
r_vis_i_d   0.116   0.116   0.116   0.115   0.113
 t_uv_o     0.000   0.000   0.000   0.000   0.000
 t_uv_i     0.000   0.000   0.000   0.000   0.000
 r_uv_o     0.000   0.000   0.000   0.000   0.000
 r_uv_i     0.000   0.000   0.000   0.000   0.000
t_uv_o_d    0.000   0.000   0.000   0.000   0.000
t_uv_i_d    0.000   0.000   0.000   0.000   0.000
r_uv_o_d    0.000   0.000   0.000   0.000   0.000
```

Figure A.6 - Part of a text file from *WIS* before being corrected.



```
prop            0      10      20      30      40
 abs    1   0.262   0.263   0.264   0.266   0.268
 abs    2   0.000   0.000   0.000   0.000   0.000
 abs    3   0.130   0.130   0.130   0.129   0.128
 abs    4   0.000   0.000   0.000   0.000   0.000
 abs    5   0.000   0.000   0.000   0.000   0.000
 abs    6   0.000   0.000   0.000   0.000   0.000
 abs    7   0.000   0.000   0.000   0.000   0.000
 t_sol_o    0.000   0.000   0.000   0.000   0.000
 t_sol_i    0.000   0.000   0.000   0.000   0.000
 r_sol_o    0.607   0.607   0.606   0.605   0.605
 r_sol_i    0.312   0.312   0.312   0.313   0.318
t_sol_o_d   0.000   0.000   0.000   0.000   0.000
t_sol_i_d   0.000   0.000   0.000   0.000   0.000
r_sol_o_d   0.392   0.392   0.391   0.389   0.384
r_sol_i_d  0.0621  0.0620  0.0618  0.0612  0.0599
 t_vis_o    0.000   0.000   0.000   0.000   0.000
 t_vis_i    0.000   0.000   0.000   0.000   0.000
 r_vis_o    0.696   0.696   0.695   0.694   0.693
 r_vis_i    0.243   0.243   0.243   0.245   0.254
t_vis_o_d   0.000   0.000   0.000   0.000   0.000
t_vis_i_d   0.000   0.000   0.000   0.000   0.000
r_vis_o_d   0.630   0.630   0.629   0.626   0.618
r_vis_i_d   0.116   0.116   0.116   0.115   0.113
 t_uv_o     0.000   0.000   0.000   0.000   0.000
 t_uv_i     0.000   0.000   0.000   0.000   0.000
 r_uv_o     0.000   0.000   0.000   0.000   0.000
 r_uv_i     0.000   0.000   0.000   0.000   0.000
t_uv_o_d    0.000   0.000   0.000   0.000   0.000
t_uv_i_d    0.000   0.000   0.000   0.000   0.000
```

Figure A.7 - Part of a text file from *WIS* after being corrected.

A.2.2 *BuildingCalc/LightCalc* - How to import the text files with the properties of the window generated in *WIS*

The way to use *BuildingCalc/LightCalc* and how to define the different settings is described in detail in the *BuildingCalc/LightCalc* userguide [11].

In this step-by-step example only the way to import the text files generated with *WIS* will be presented.

1) Start *BuildingCalc/LightCalc* (in **Figure A.8** it is presented the *BuildingCalc/LightCalc* interface).

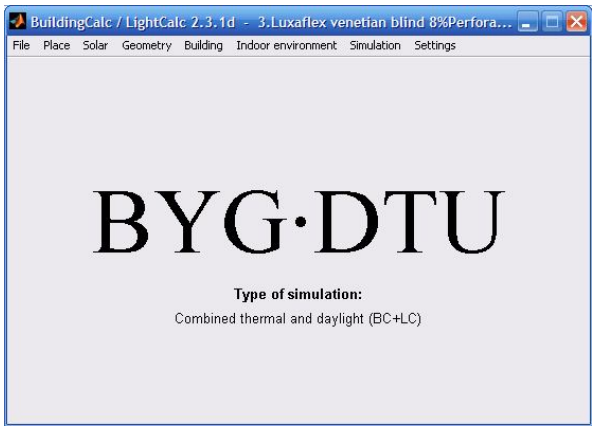

BuildingCalc / LightCalc 2.3.1d - 3.Luxaflex venetian blind 8%Perfora...
File Place Solar Geometry Building Indoor environment Simulation Settings
BYG·DTU
Type of simulation:
Combined thermal and daylight (BC+LC)

Figure A.8 - *BuildingCalc/LightCalc* interface

2) In the menu *File*, click on *Type of Project*. Choose *Combined Simulation* (BC+LC).

3) Click on the option *Glazings* in the menu *Building* (the window presented in **Figure A.9** will be displayed)

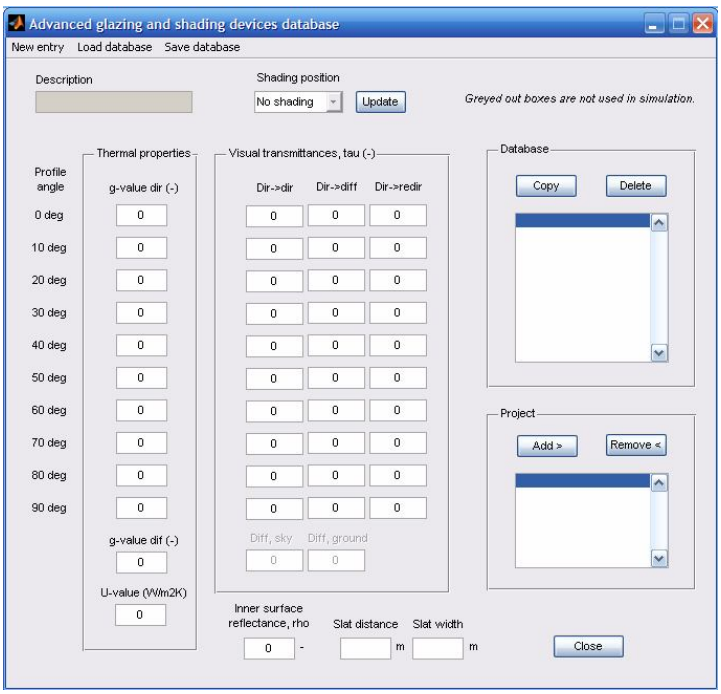


Figure A.9 - *Glazings* window from *Building* menu.

3) Press the option *New entry*. A window as the one in **Figure A.10** will be displayed.
In the box “Glazing and shading” choose *blinds* as the *shading device* and choose *Load data from file*.
For the *clear glazing* load the text file for the glazing (without shading) generated with *WIS*. For the *shading input* load the 11 files (-90º, -80º, -60º, -40º, -20º, 0, 20º, 40º, 60º, 80º, 90º) created for the system glazing + shading in different slats positions. (see **Figure A.11**)
Press *Load* button. Press *OK* to return to the *Glazings* window.
4) Press the button *Save database* and choose a name for the database.

5) Now the created system can be added to the *Project*.
As defined this system has different positions (only glazing or glazing + shading with different slats angles). During the yearly simulations *BuildingCalc/LightCalc* will choose the most appropriate for each hour.

6) Everytime a *New entry* is added, before adding it to the *Project* the *Database* must be saved.

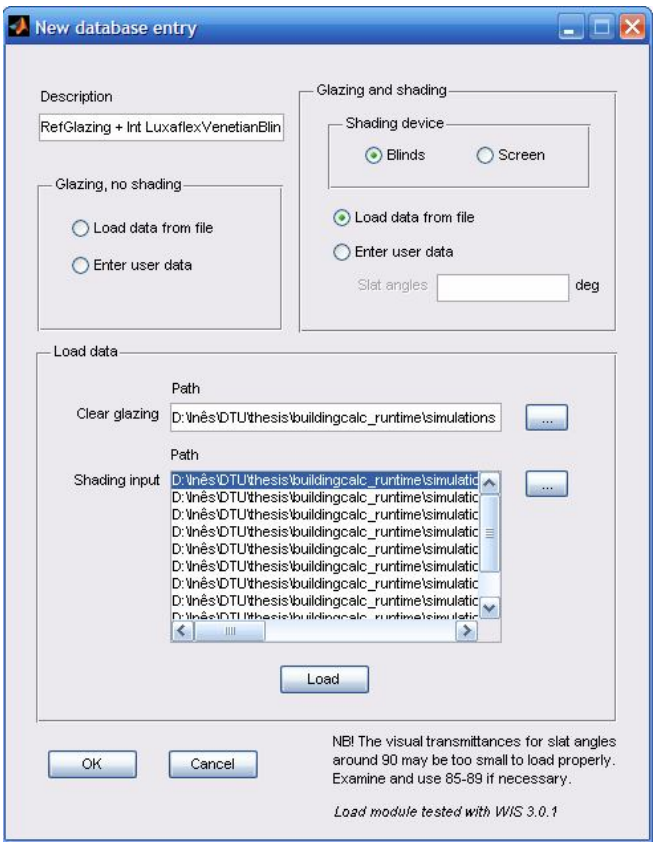


Figure A.10 - *New entry* window

Appendix B - How to add a new shading system to *WIS*

It is possible to add new solar shading systems to the *WIS* database.

This procedure may be done in two different ways:

1) Inserting data manually

2) Importing a text file

B.1 Inserting data manually

This is the easiest way of defining a new solar shading system in the *WIS* database:

1) Open the *Scattering layer* window

2) Create a new record, select the type of shading system and insert the following information: *Product information*, *Geometry*, *Thermal properties* and *Optical Properties*.

The *Optical properties* can be set in two distinct ways: as spectral data or as integrated data.

To input the spectral data a table as the one presented in **Figure B.1** should be filled in: for each wavelength the optical properties for the normal incidence angle should be defined.

The way to define the integrated data is different when comparing a roller blind with a slat shading system: for a roller blind the integrated optical properties must be set for different incidence angles (as shown in **Figure B.2**), while for a slat shading device only the optical properties for the normal angle of incidence must be set (see **Figure B.3**).

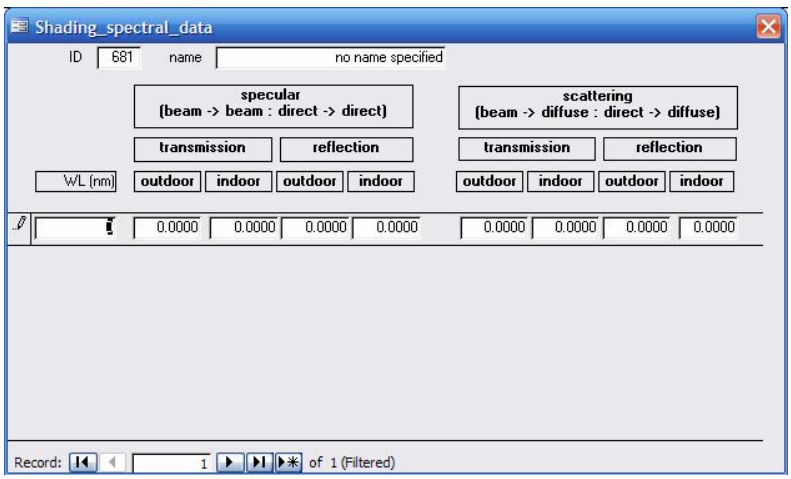


Figure B.1 - Table where the spectral data for the new shading system are defined (valid for roller blinds and slat shading systems)

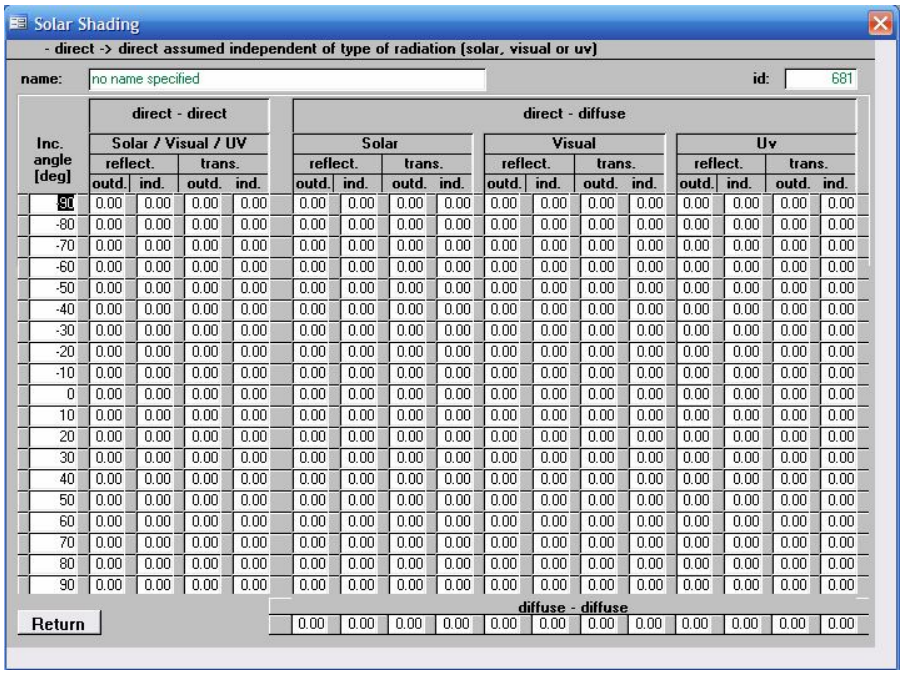


Figure B.2 - Table where the integrated data for a new roller blind system are defined (for different angles of incidence)

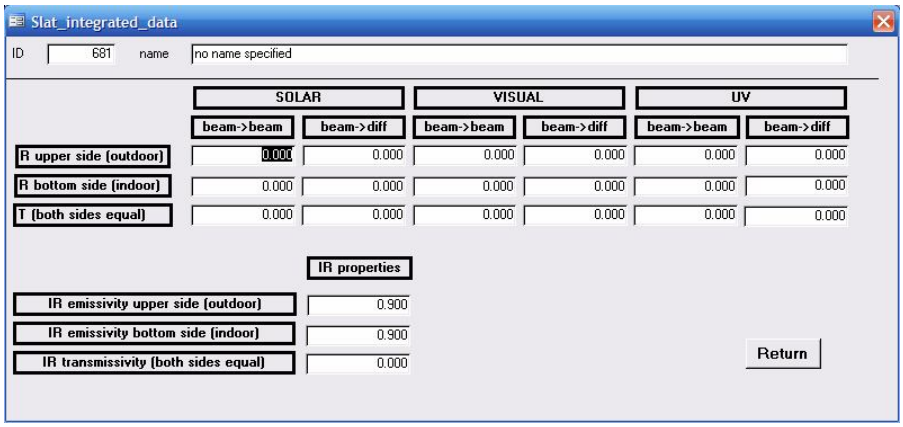


Figure B.3 - Table where the integrated data for a new slat shading device are defined (only normal angle of incidence)

B.2 Importing a text file

This is a different way of adding a new shading system to the *WIS* database.

The first step is to create a text file with the format of the examples presented on [17].

To import the text file to *WIS* database the procedure next presented must be followed:

1) On the Scattering layer window create a new record.

2) Click on the button *Import from text file*. A new window will be displayed: answer *Yes*. The *WIS* database manager will be initialized.

3) On the *WIS* database manager choose *File>Open>WIS database*.
Open the database that you are currently using is *WIS*: by default its name is *WISDATA.mdb*.

4) Now you need to open the text file you created before. Choose *File>Open>Text files*.
A new window will be presented. Select *Spectral shading data.*
Next, select the text file you created and open it. The content of the text file will be presented in the right window.

5) In the left window go one level up by clicking on the folder where your text file is stored. The content of the text file will disappear from the right window and only its name will be shown.

6) In the right window select the text file and choose: *Menu>Edit>Copy Records*.

7) Go to the *WISDATA.mdb* in the left window and choose *shadings*. Choose *Menu>Edit>Paste records*.

8) The database manager will now request you to type in a groupname (groupname WinDat is not allowed). The data will be pasted to the shadings database.

9) Now the new shading file is available in the *Scattering layers* database and ready to be used.

Appendix C - Example of how to model glass lamellas from glass pane properties in *WIS*

The glass lamellas are not available on the *WIS* database.
However they can be generated from the properties of a glass pane: a text file with the properties of the glass lamellas (defined as a slat system) can be created and imported to the *shading database*.

Next, it is described a step-by-step example on how to make use of the properties of a glass pane to create a glass lamellas text file. The glass lamellas presented are made from the Saint Gobain Glass Antelio Silver.

1) Open the *Specular Pane* window.

2) Look for the *SGG Antelio Silver* pane and make it active (as shown in **Figure C.1**).

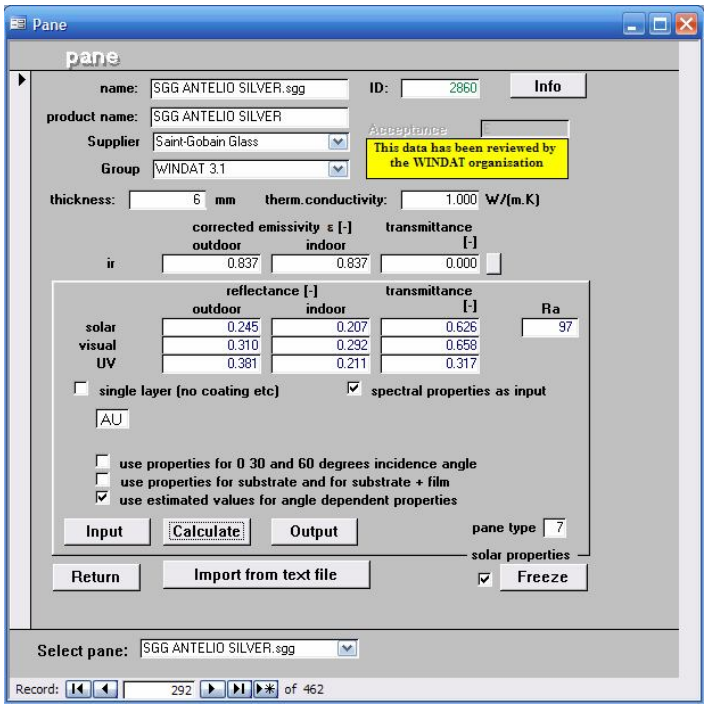


Figure C.1 - *Specular pane* window with *SGG Antelio Silver* pane active

3) Click on *Calculate*. A window as the one in **Figure C.2** will be presented: mark the boxes B*asics* and S*pectral* and click on *Create*.

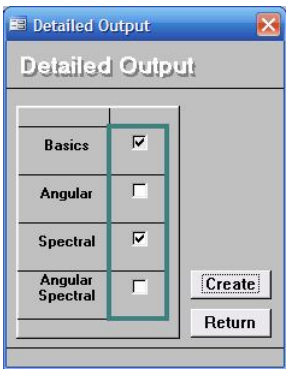


Figure C.2 - *Calculate* window

3) A text file with the properties of the glass will be generated.
Copy to a new text file only the data organized in columns under the title *Spectral Properties Total Solar* (four columns must be copied: *Wavel*, *Transm*, *Refl_o*, *Refl_i;* wavelength varying from 300nm to 2500nm). Save the new text file.

4) Open the new text file in *Microsoft Excel*. Follow the steps to assure that each value will be placed in a different cell.
Now that the spectral data from the glass pane is in *Microsoft Excel* it is easier to treat it in order to create the file for the glass lamellas.

5) In the text file for the glass lamellas the columns with the spectral data must be nine (see **Table C.1**). Add the columns that are missing in Microsoft Excel interface.
Assume that the front and back surfaces transmittances are both equal to the glass pane transmittance and assume that the transmittance and reflectance are always direct and never diffuse.

Table C.1 - Columns needed for the glass lamellas text file

Column number	Content	Description
1	Wavelength	
2	$Tf_{n,\ dir}$	Direct transmittance, front surface
3	$Tf_{n,\ diff}$	Diffuse transmittance, front surface
4	$Tb_{n,\ dir}$	Direct transmittance, back surface
5	$Tb_{n,\ diff}$	Diffuse transmittance, back surface
6	$Rf_{n,\ dir}$	Direct reflectance, front surface
7	$Rf_{n,\ diff}$	Diffuse reflectance, front surface
8	$Rb_{n,\ dir}$	Direct reflectance, back surface
9	$Rb_{n,\ diff}$	Diffuse reflectance, back surface

6) Copy the new columns to *Notepad* and create a text file as the one presented in **Figure C.3**. (the characteristics of this file are in accordance with the models described on [17])

```
{ Units: Nanometers }
{ Manufacturer: Saint Gobain }
{ Product name: SGG Antelio Silver }
{ Product type: 1 }
{ Position: 1 }
{ Material: Glass}
{ Appearance: Clear }
{ Thickness: 8 }
{ Conductivity: 1 }
{ Emissivity front: 0.85 }
{ Emissivity back: 0.85 }

300     0       0       0       0       0.256   0       0.047   0
320     0.006   0       0.006   0       0.275   0       0.047   0
340     0.252   0       0.252   0       0.375   0       0.115   0
360     0.477   0       0.477   0       0.428   0       0.325   0
380     0.499   0       0.499   0       0.432   0       0.353   0
400     0.551   0       0.551   0       0.42    0       0.389   0
420     0.563   0       0.563   0       0.409   0       0.375   0
440     0.577   0       0.577   0       0.391   0       0.359   0
460     0.598   0       0.598   0       0.374   0       0.352   0
480     0.614   0       0.614   0       0.36    0       0.342   0
500     0.632   0       0.632   0       0.345   0       0.33    0
520     0.645   0       0.645   0       0.331   0       0.318   0
540     0.657   0       0.657   0       0.32    0       0.304   0
560     0.665   0       0.665   0       0.306   0       0.29    0
580     0.671   0       0.671   0       0.294   0       0.276   0
600     0.671   0       0.671   0       0.283   0       0.262   0
620     0.674   0       0.674   0       0.274   0       0.247   0
640     0.668   0       0.668   0       0.263   0       0.232   0
660     0.669   0       0.669   0       0.253   0       0.219   0
680     0.666   0       0.666   0       0.245   0       0.207   0
700     0.66    0       0.66    0       0.234   0       0.195   0
720     0.656   0       0.656   0       0.228   0       0.183   0
740     0.644   0       0.644   0       0.219   0       0.172   0
760     0.644   0       0.644   0       0.211   0       0.162   0
780     0.633   0       0.633   0       0.204   0       0.153   0
800     0.632   0       0.632   0       0.197   0       0.144   0
850     0.6     0       0.6     0       0.171   0       0.119   0
900     0.599   0       0.599   0       0.178   0       0.12    0
950     0.594   0       0.594   0       0.164   0       0.114   0
1000    0.594   0       0.594   0       0.155   0       0.109   0
1050    0.597   0       0.597   0       0.146   0       0.103   0
1100    0.603   0       0.603   0       0.139   0       0.1     0
1150    0.61    0       0.61    0       0.133   0       0.098   0
1200    0.619   0       0.619   0       0.129   0       0.096   0
1250    0.631   0       0.631   0       0.123   0       0.095   0
1300    0.646   0       0.646   0       0.119   0       0.093   0
1350    0.662   0       0.662   0       0.116   0       0.093   0
1400    0.678   0       0.678   0       0.115   0       0.095   0
1450    0.699   0       0.699   0       0.116   0       0.096   0
1500    0.72    0       0.72    0       0.112   0       0.097   0
1550    0.737   0       0.737   0       0.11    0       0.097   0
1600    0.747   0       0.747   0       0.107   0       0.097   0
1650    0.755   0       0.755   0       0.106   0       0.095   0
1700    0.76    0       0.76    0       0.104   0       0.094   0
1750    0.758   0       0.758   0       0.1     0       0.092   0
1800    0.76    0       0.76    0       0.1     0       0.091   0
1850    0.76    0       0.76    0       0.098   0       0.089   0
1900    0.757   0       0.757   0       0.094   0       0.085   0
1950    0.759   0       0.759   0       0.1     0       0.091   0
2000    0.76    0       0.76    0       0.094   0       0.085   0
2050    0.762   0       0.762   0       0.092   0       0.083   0
2100    0.762   0       0.762   0       0.089   0       0.082   0
2200    0.739   0       0.739   0       0.085   0       0.079   0
2300    0.751   0       0.751   0       0.084   0       0.077   0
2400    0.751   0       0.751   0       0.081   0       0.08    0
2500    0.735   0       0.735   0       0.081   0       0.068   0
```

Figure C.3 - Text file for the glass lamellas composed of SGG Antelio Silver

7) Now that the text file for the glass lamellas is created it can be imported to *WIS* database as previously referred on **APPENDIX B - B.2 Importing a text file** and used as a slat shading system.

8) In the *Scattering layer* window, with *SGG Antelio Silver* activated, set the geometric properties of the glass lamellas as shown in **Figure C.4** (the geometric properties could also be included in the text file). As for the slat shading system, also the glass lamellas the angle can be changed in order to create the different files to input in *BuildingCalc/LightCalc*.

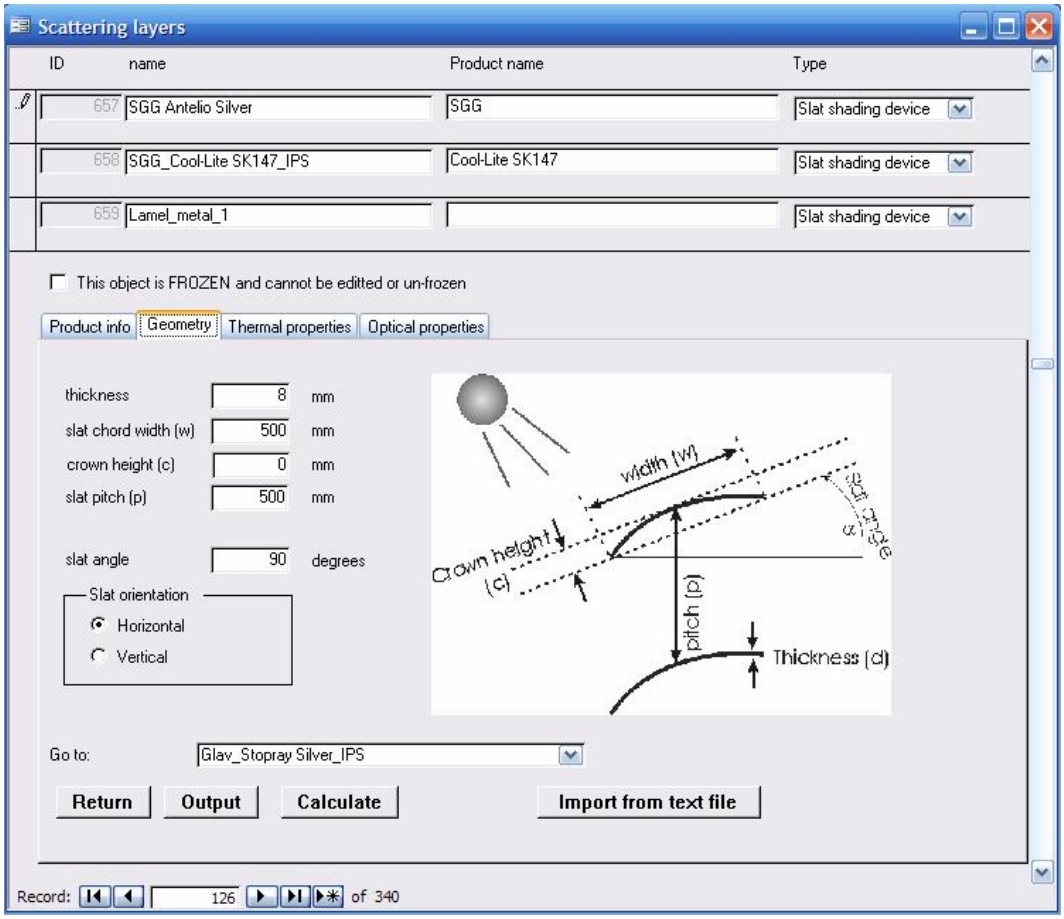


Figure C.4 - Geometric properties for the SGG Antelio Silver glass lamellas

Appendix D - Tips on how to import the glass lamellas to *BuildingCalc/LightCalc*

The way to import the text files generated from *WIS* to *BuildingCalc/LightCalc* is approximately the same as described on **APPENDIX 2 (A.2.2 *BuildingCalc/LightCalc* - How to import the text files with the properties of the window generated in *WIS*)**.

Also for the glass lamellas different text files must be generated in *WIS* for different slats angles

However, when importing to *BuildingCalc/LightCalc* the *WIS* text files, the file that must be loaded for the *clear glazing* is not the glazing without shading but the glazing with the glass lamellas opened (slat angle of 0º). The reason for this is that the glass lamellas are not retractable.

After loading the files a correction must be made:
For the *shading position>no shading* (red square in **Figure D.1**) the properties must be reinserted manually and equal to *shading position>0* (red square in **Figure D.2**).
The result must be **Figure D.3**.

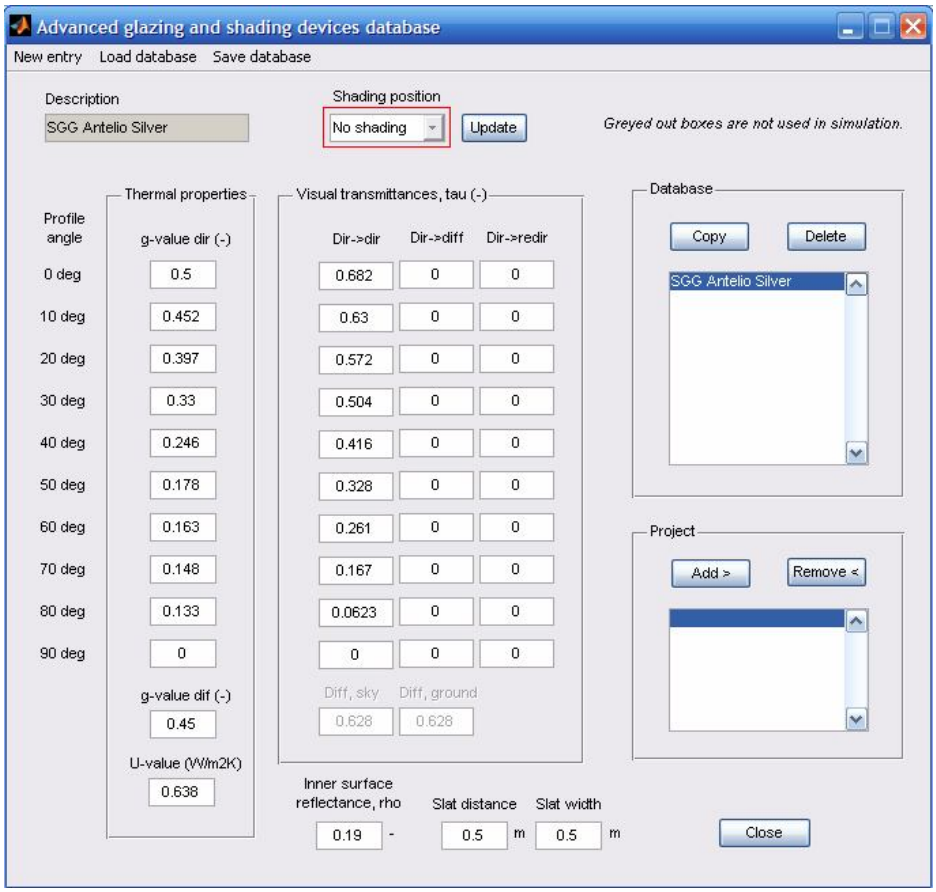


Figure D.1 - Shading position > no shading - before correction

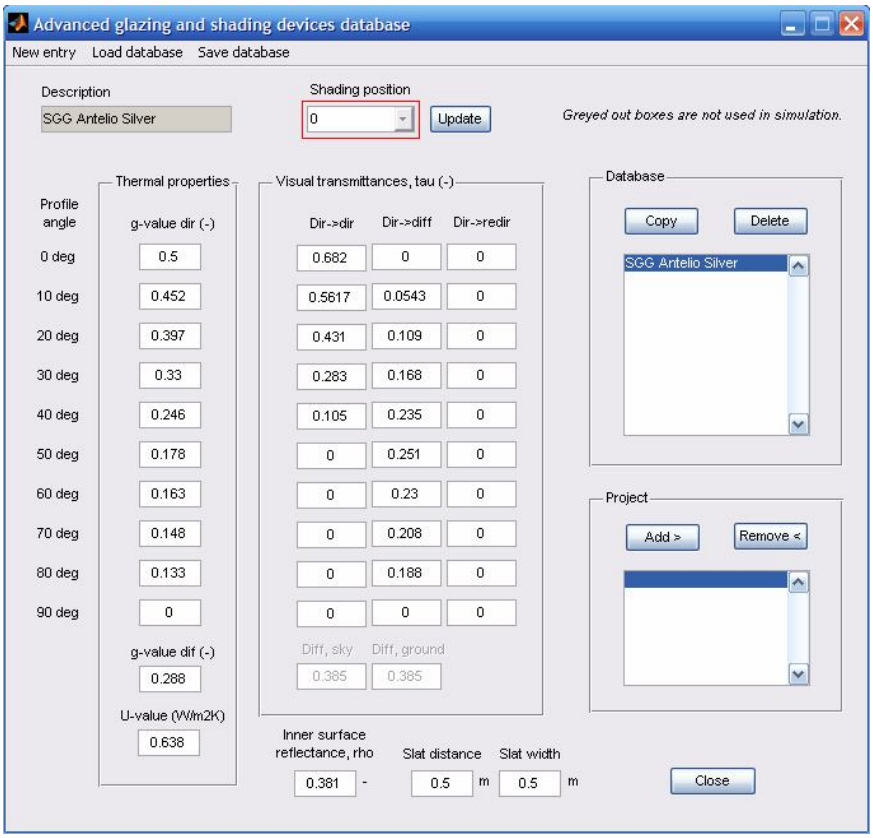


Figure D.2 - Shading position > 0

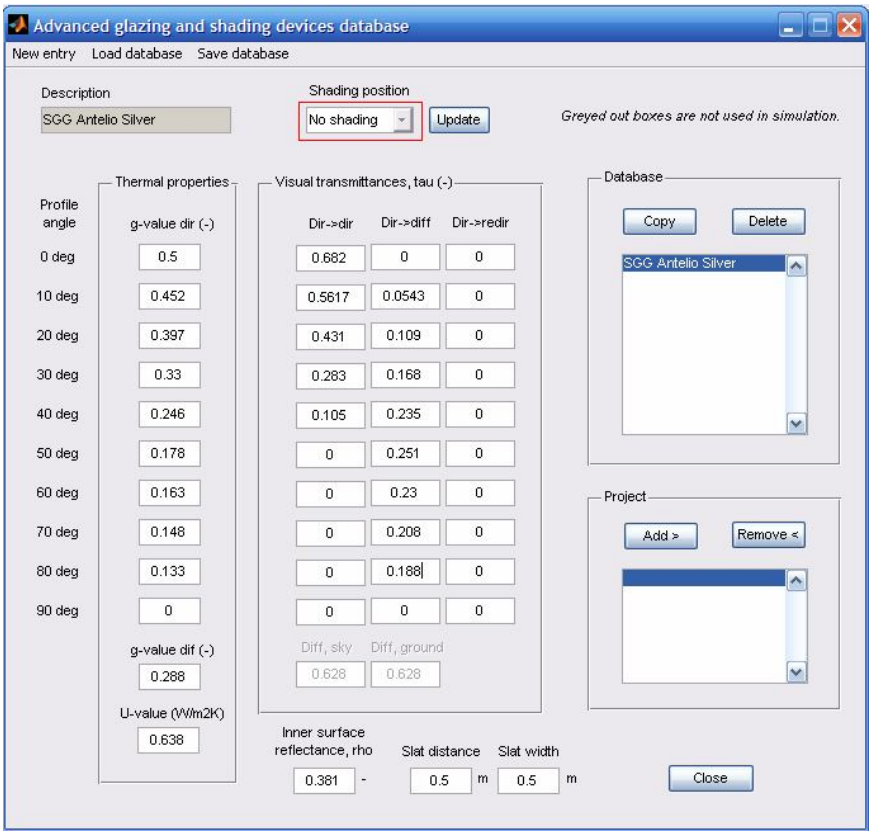
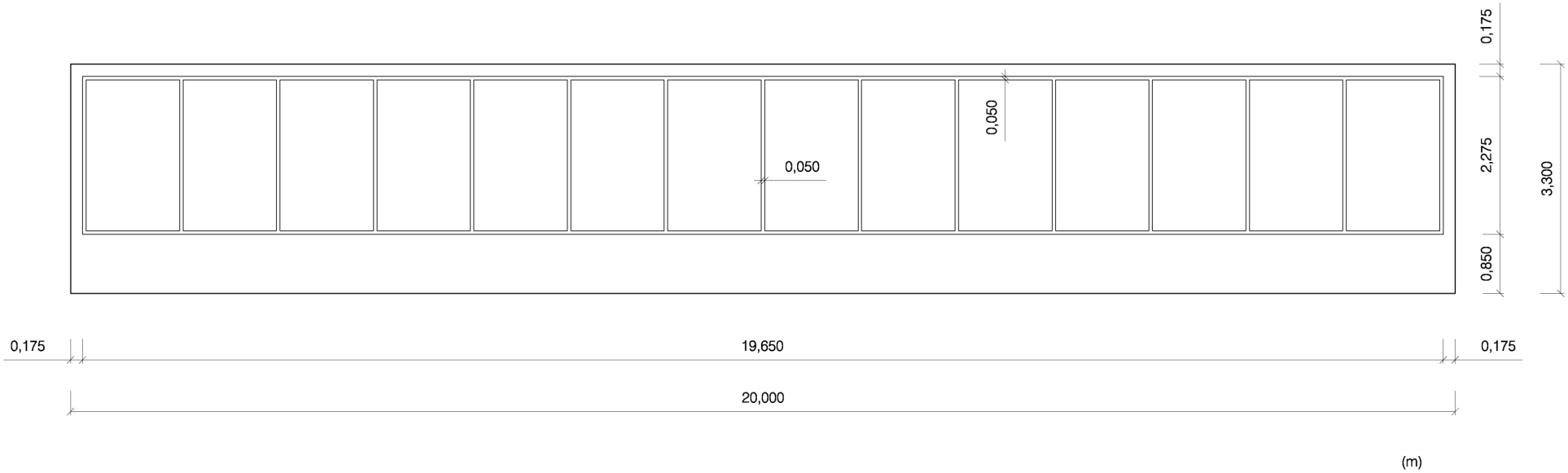


Figure D.3 - Shading position > no shading - after correction

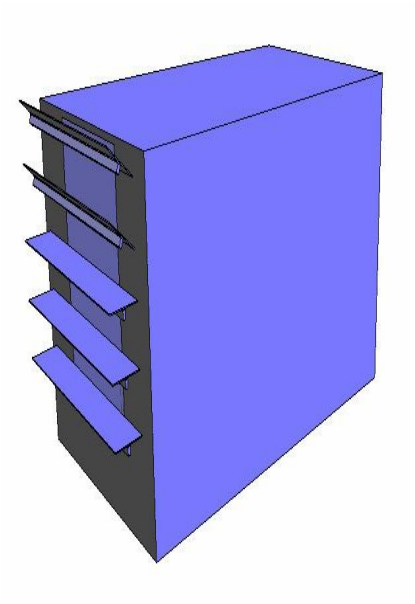
Appendix E - Detailed drawing of the façade

E-1

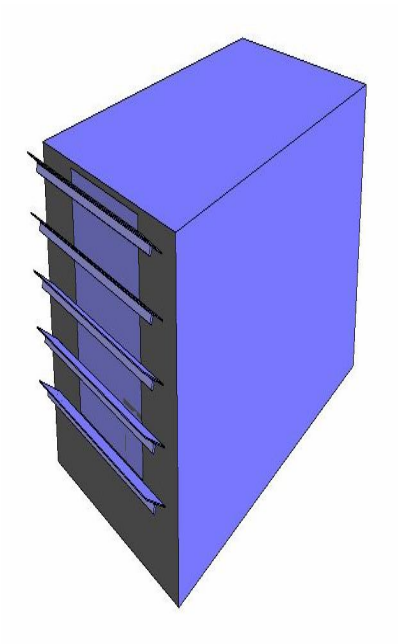


Appendix F - IESve models of the test room for Cases 1, 2, 3 and 4

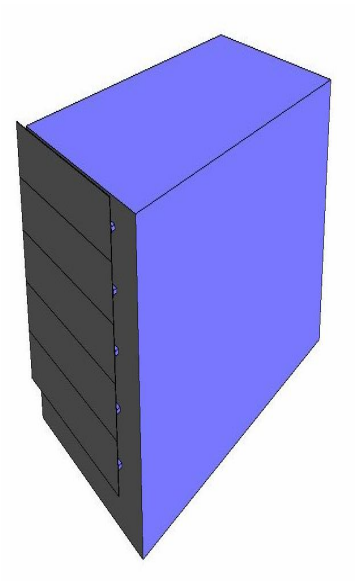
CASE 1



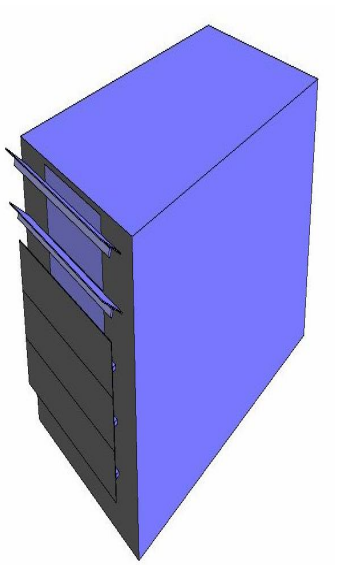
CASE 2



CASE 3



CASE 4



Appendix G - Examples of virtual images of the experimental rooms generated by *IESve/Radiance*

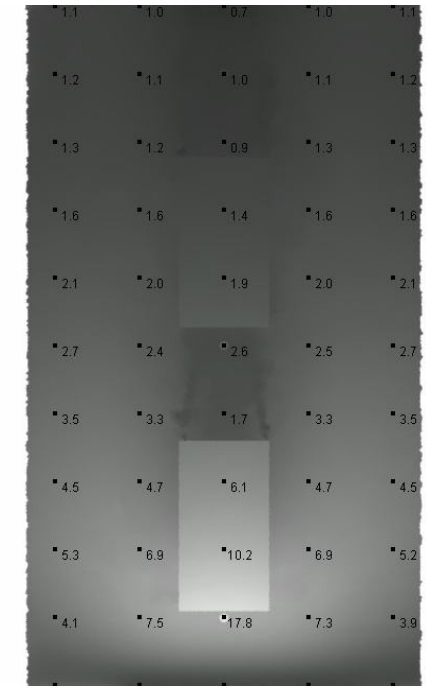


Figure G.1 - Reference room under overcast sky for Case 2 - Daylight factor values [%]

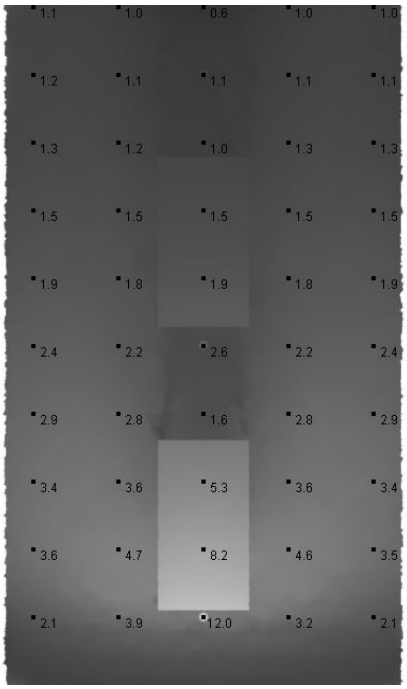


Figure G.3 - Test room under overcast sky for Case 2 - Daylight factor values [%]

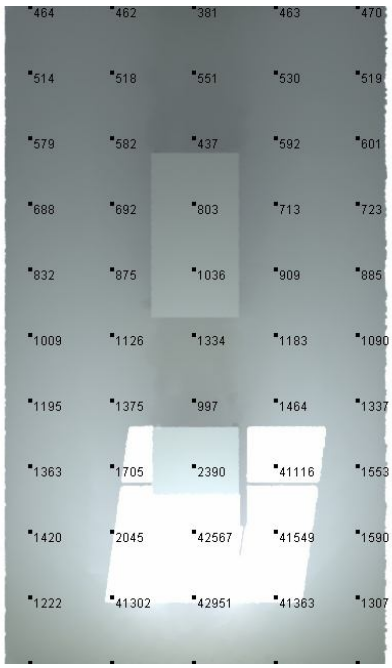


Figure G.2 - Reference room under sunny sky for Case 4 (May 18th 2007 at 13.07) – Illuminance values [lux]

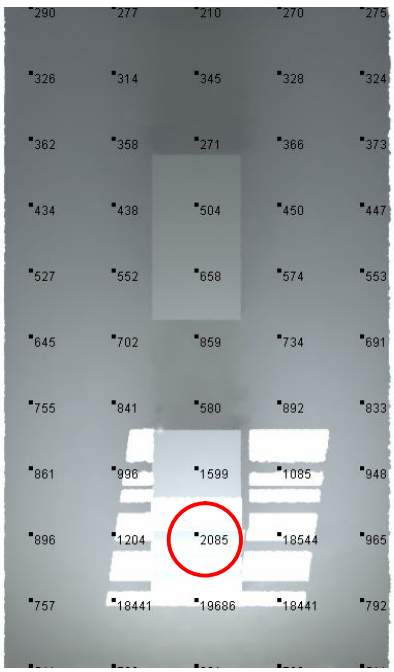


Figure G.4 - Reference room under sunny sky for Case 4 (May 18th 2007 at 13.07) – Illuminance values [lux]